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ABSTRACT

In this second volume of a three volume study of a collegiate level computer-assisted instruction (CAI) course in undergraduate physics the course objectives are summarized and the learning materials and evaluative instruments used in the study are presented. For a complete description of the project see volume one (EM009605). For the computer programs developed for the course see volume three (EM009607). (JY)

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FLORIDA STATE UNIVERSITY

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RESEARCH AND IMPLEMENTATION OF COLLEGIATE INSTRUCTION OF PHYSICS VIA COMPUTER-ASSISTED INSTRUCTION

VOLUME II

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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November 15, 1968

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Computer-Assisted Instruction Center
Florida State University
Tallahassee, Florida

TECH REPORT SERIES

The FSU CAI Tech Report Series is intended to communicate the research findings from studies and sponsored projects that have direct implication for the role of computers in education and training. The rationale for the tech report series is fourfold. First, the tech reports provide a convenient document format for reporting the results of all phases of large CAI projects. These projects typically span too many areas to be reduced into the more conventional research article format. Second, major computer systems designs will be presented in their entirety within the tech report series. Third, this series will provide colleagues at the FSU CAI Center an opportunity to develop major conceptual papers relating to all phases of computers and instruction. And fourth, all of the dissertations performed at the CAI Center will be published within this series.

In terms of content, one can anticipate a detailed discussion of the rationale of the research project, its design, a complete report of all empirical results as well as appendices that describe in detail the CAI learning materials utilized. It is hoped that by providing this voluminous information other investigators in the CAI field will have an opportunity to carefully consider the outcomes as well as have sufficient information for research replication if desired. Any comments to the authors can be forwarded via the Florida State University CAI Center.

Duncan N. Hansen

Director

Computer Assisted Instruction Center

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PREFACE

This report represents a long and diligent effort on the part of many individuals at Florida State University to investigate in a substantial manner the developmental and effectiveness factors in a collegiate level Computer-Assisted Instruction course in undergraduate physics. The challenge of creating a course for a computer-based presentation, especially at the beginning of the project in 1966, were considerable. The project was arduous both in terms of its size and challenge because of the full commitment to investigate all phases of the development, execution, revision and cost effectiveness of the CAI Physics Course from a research point of view. We trust that this report sufficiently describes the findings and proves useful to educators and researchers in terms of understanding the nature of CAI curriculum development as well as some possible implications as to its positive pay-off for collegiate instructions.

Past experience has indicated that a wide variety of scientists and educators will be interested in this report. Consequently, we have organized the final report into three parts in order to facilitate better dissemination. Volume I consists of the main body of the report. This covers the topics of 1) the statement of the problem, 2) the background literature, 3) the developmental curriculum processes, 4) a description of the multi-media techniques used within the course, 5) a set of CAI physics problem exercises, and, then, 6) the three subsequent field studies. Volume I is concluded with a presentation on cost analysis and a statement of what we consider the important conclusions. Volume II presents the appendices that describe in complete detail the nature of the learning materials and evaluative instruments utilized. This covers such topics as the course objectives, the data management system utilized for course monitoring and revision, booklet utilized by the students, presentation of audio lectures, homework problems, descriptions of films plus personality and attitude instruments. Volume III is a presentation of the CAI curriculum. This is broken up into two parts, that is, the 1500 CAI course and the problem sets presented via the 1440 computer. We trust this organization will prove useful to the different types of readers who would not want to be burdened with extra material unless they have an express purpose for it.

We wish to thank USOE and personnel in the Bureau of Research who have patiently advised and critiqued this project. We especially wish to thank Dr. Louis Bright for helping in the initiation of the project, plus Dr. Howard Hjelm, Dr. Andrew Molnar, Dr. William Adrian, and Dr. Howard Figler for their continuing interest and advice.

Here at Florida State University we wish to thank Dr. Steven Edwards, Dr. Gunter Schwarz, Dr. William Nelson, Dr. Neil Fletcher, and Dr. Robert Kromhout of the Department of Physics. Their conceptional advice, editorial assistance, and continuing interest were invaluable to the execution of this research project. We wish to thank Mrs. Ora Kromhout, Albert Griner, Joseph Betts, Marjorie Nadler, and Robert Hogan who authored the CAI materials. We wish to thank Mrs. Betty Wright, Mrs. Charlotte Crawford, and Mrs. Sharon Papay for their diligent efforts in coding and debugging the CAI course material. In turn, we wish to thank Mr. Beverly Davenport, Mr. Eugene Wester, and Mr. Wayne Lee for their efforts in developing the computer programs, especially in the area of data analysis, that allowed for the course revision. We wish also to thank our numerous, invaluable graduate students who contributed instrumentally in the development of the project. These were Kenneth Majer, Harold O'Neil, Leroy Rivers, Paul Gallagher, James Papay, and William Harvey. And lastly, the help of our secretaries in both the preparation and editing of this report was invaluable. We, therefore, wish to thank Louise Crowell, Dorothy Carr, Harvey Varner, Mary Calhoun and Ann Welton.

We trust that the findings from this report will prove useful and represents a sound investment on the part of the Bureau of Research of the U. S. Office of Education.

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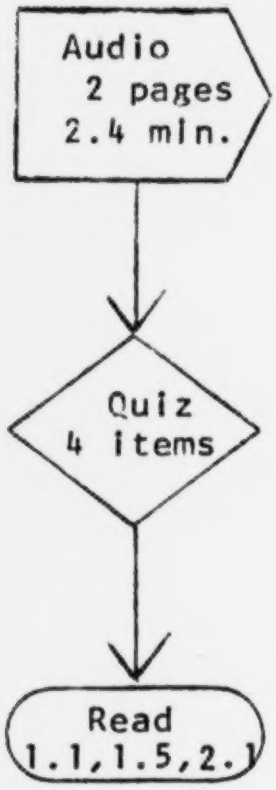
APPENDIX A

COURSE OBJECTIVES

Lesson Number: 1
Lesson Title: Introduction



OBJECTIVE:

Introduction to Physics and tools needed to study physics (physics: the fundamental science of the natural world which deals with time, space, motion, matter, electricity, light, and radiation. The tools needed are a system of measurement and mathematics.)

Concept of Measurement (expression of the need to quantify in order to benefit from usefulness of mathematics).

Mathematics--described as a language of description.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

None.

CONCEPTS TO BE ACQUIRED:

Primary tasks of a physicist:

1. Observation of phenomena--tools are the instrumentation and basic laws of physics (which is the subject under discussion).
2. Measurement and description of phenomena--tools are the system of measurement and mathematics.

Need for a well-defined system of measurement through which:

characteristics may be	quantified
composition	mass
size	length
position	time

Three fundamental quantities through which characteristics may be quantified: mass, length, time.

System of basic units or building blocks for measuring the fundamental quantities:

quantity	unit
mass	kilogram
length	meter
time	second

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

What are the three basic quantities which are used to describe phenomena occurring in the natural world? (mass, length, time)

What units are used to measure these quantities? (kilogram, meter, second)

Lesson Number: 2
Lesson Title: Scientific Notation

OBJECTIVE:

Introduce the correct scientific notation --one digit to the left of the decimal point, significant digits multiplied by a positive ten which has been raised to the appropriate positive or negative power.

Define "order of magnitude" (nearest power-of-ten derived from quantity expressed in scientific notation).

Demonstrate arithmetic operations on quantities expressed in scientific notation (addition, subtraction, multiplication, division, and exponentiation).

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Basic arithmetic skills--addition, subtraction, multiplication, division and exponentiation.

Familiarity with elementary, linear algebra--expressed by ability to solve linear equations of the general form:

$$Ax + B = y$$

CONCEPTS TO BE ACQUIRED:

Recognition of correct scientific notation format. Examples: 1.967×10^3, 2.06×10^{-3}, 7.3×10^1, 8.0×10^1

Calculation with quantities expressed in scientific notation:

Addition: $70 + 5.6 = 7.0 \times 10^1 + 0.56 \times 10^1 = 7.56 \times 10^1$

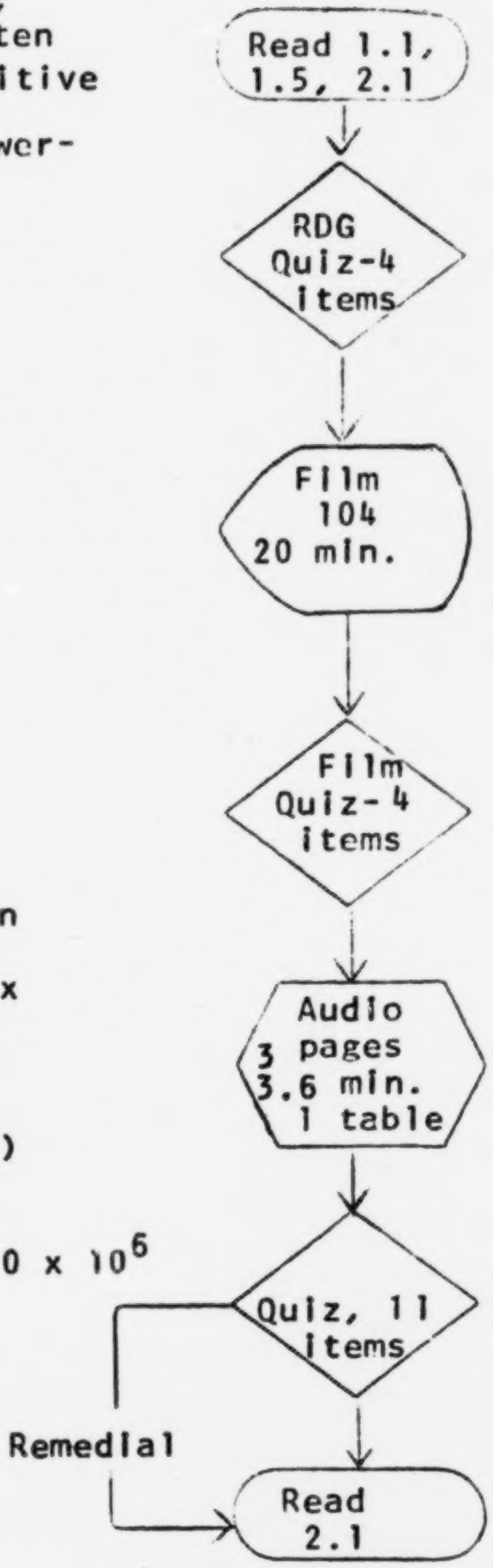
Subtraction: $350-5 = 3.50 \times 10^2 - 0.05 \times 10^2 = 3.45 \times 10^2$

Multiplication: $317 \times 45 = (3.17 \times 10^2)(4.5 \times 10^1) = 14.265 \times 10^3 = 1.43 \times 10^4$

Division: $$\frac{320 \times 10^2}{16 \times 10^{-3}} = \frac{3.2 \times 10^4}{1.6 \times 10^{-2}} = 2.0 \times 10^6$$

Recognition of order of magnitude:

Number	Order of Magnitude
3.17×10^2	10^2
9.7×10^2	10^3
5.5×10^2	10^3
3.17×10^{-2}	10^{-2}
5.5×10^{-2}	10^{-1}



ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Evaluate $\dfrac{(17.3 \times 10^3 + 3.5 \times 10^{-2})(3156)}{747 - 6.5 \times 10^2}$

Given a list of numbers, what is the order of magnitude of each number?

Lesson Number: 3
Lesson Title: Scaling and Scale Models

OBJECTIVE:

Demonstrate the usefulness of scale models --advantages of reduced experimental costs.

Explain the relationships between physical dimensions and physical characteristics-- linear dimensions and their relationships to surface area, volume, strength, weight, heat loss, and heat production.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

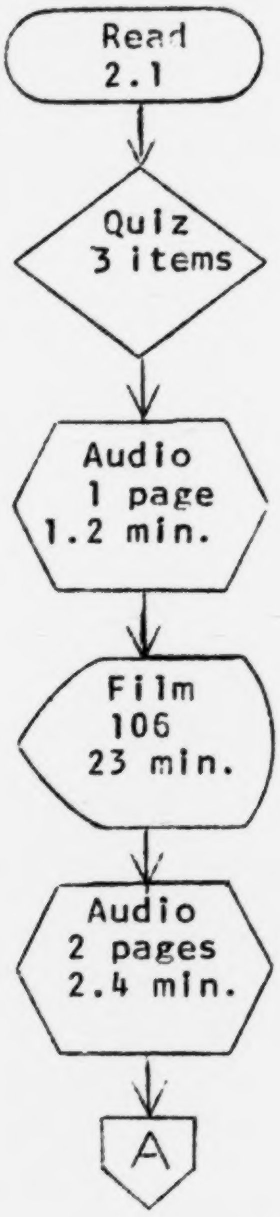
Functional relationships and proportions:

1. direct proportion - $a \propto b$ which implies $a = kb + n$
2. inverse proportion - $a \propto \frac{1}{b}$ which implies $a = \frac{k}{b} + n$

CONCEPTS TO BE ACQUIRED:

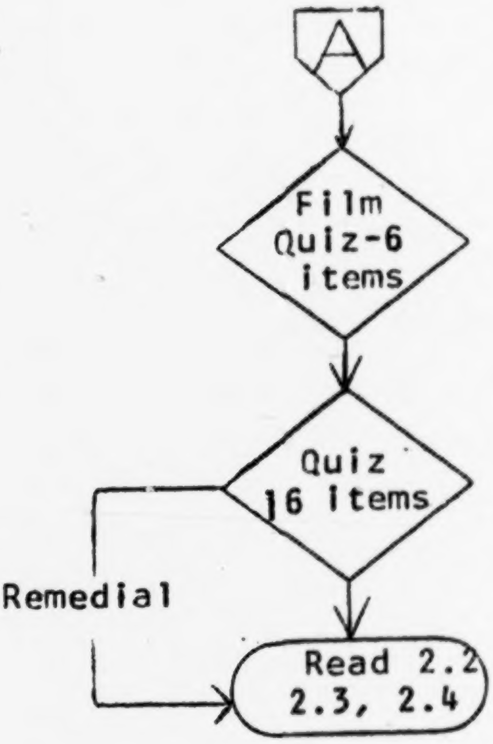
Effect upon physical characteristics caused by variations in linear dimensions (denoted by x) Proportional to:

length	x
surface area	x^2
cross surface area	x^2
volume	x^3
strength	x^2
weight	x^3
heat loss	x^2
heat production	x^3



ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

How would a change in the linear dimensions of an object affect length, surface area, cross sectional area, volume, strength, weight, heat loss, and heat production? (x, x^2, x^2, x^3, x^2, x^3, x^2, and x^3)



Lesson Number: 4
Lesson Title: Vectors

OBJECTIVE:

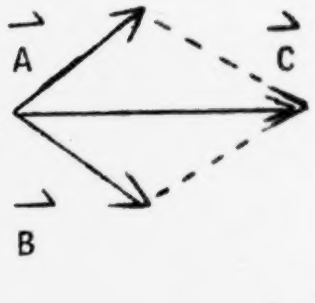
Define a Vector--a quantity having magnitude and direction.

Demonstrate arithmetic operations which may be performed on vectors:

multiplication by quantities having magnitude but not direct
(scalars) $\vec{V} = 6\vec{v}_x + 4\vec{v}_y$

$$6\vec{V} = 36\vec{v}_x + 24\vec{v}_y$$

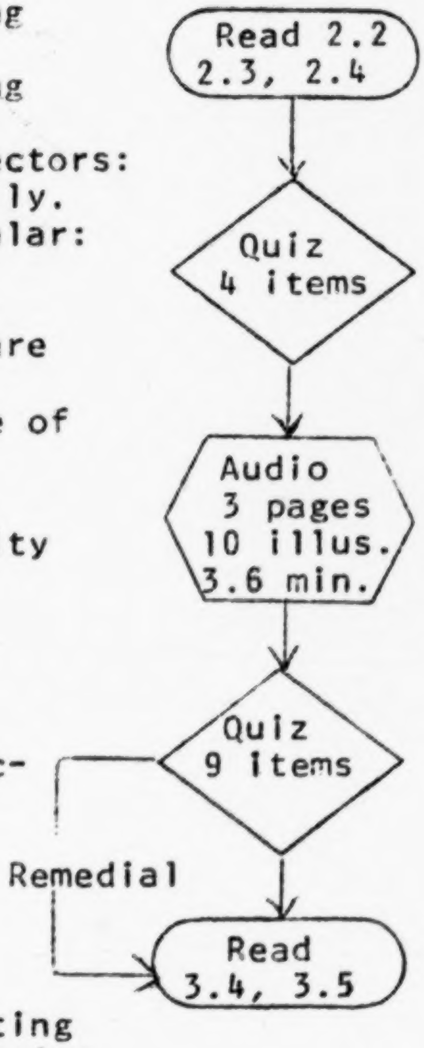
addition of vectors: $\vec{A} + \vec{B} = \vec{C}$



CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Elementary trigonometry--familiarity with sine, cosine and tangent of an angle.

CONCEPTS TO BE ACQUIRED:



Definition of a vector: quantity having magnitude and direction.

Definition of a scalar: quantity having magnitude only.

Steps in addition and subtraction of vectors: separate into components and add algebraically.

Effect of multiplying a vector by a scalar: changes the magnitude of the vector only; direction stays constant.

Exposure to physical quantities which are vectors: velocity, force and acceleration.

Definition of acceleration as time rate of change of velocity $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$

Definition of acceleration due to gravity as $9.8\ m/sec^2$.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Define a vector.

Define a scalar.

Identify those quantities which are vectors from the following list: mass, force, acceleration, velocity, volume, etc. The three that are underlined must be identified.

Students must be able to find the resultant vector from a series of vectors mentioned in a word problem. Suppose, starting at the Westcott Building, you take the following walk: you walk 1 block north, 1 block east, 2 blocks north, 2 blocks west, 1 block south, 2 blocks east, 2 blocks south, and 1/2 block west. Your net displacement at the end of your trip is (1/2 block east).

Time rate of change of velocity is (acceleration).

The acceleration due to gravity is ($9.8\ m/sec^2$).

Lesson Number: 5
Lesson Title: Elements, Molecules, Crystals, Atoms and Gases

OBJECTIVE:

Introduce physical characteristics of matter--composition, states of existence, and universal property of an object (mass).

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

None.

CONCEPTS TO BE ACQUIRED:

Definitions through which the composition of an object may be specified: all matter is made up of elements--substance that cannot be further divided chemically;
atoms--smallest piece of an element which retains its identity;
molecules--smallest piece of a compound which retains its identity.

Matter may exist in one of three physical states at a given time:
solid--defined as a crystalline substance, molecules immobile;
liquid--molecules spaced apart from each other and capable of motion;
gas--molecules widely spaced apart and capable of much motion;
crystalline substance--particles rigidly and closely packed in fixed geometrical arrays.

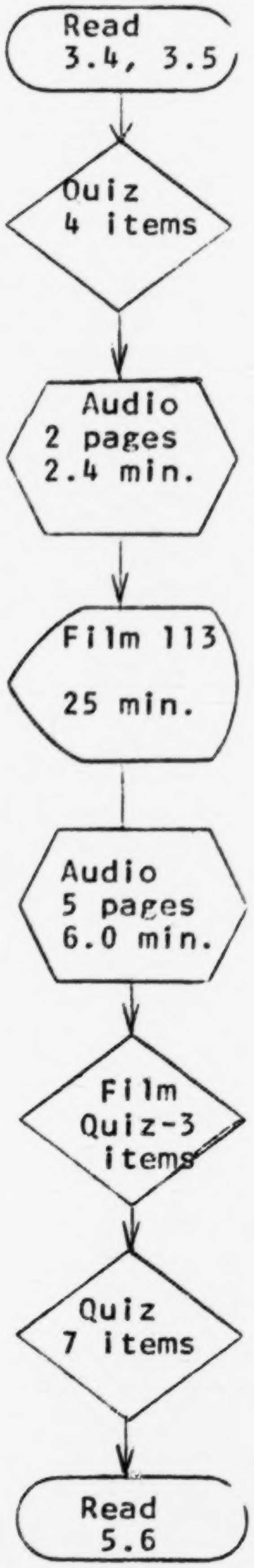
Universal, unchanging property of matter is its mass. Mass is a comparative measure of matter. Measurement is done on a beam balance wherein standard reference masses are employed.

Pressure, volume and temperature relationships for gaseous substances. (Expressed in form of Ideal Gas Law, pV = RT.)

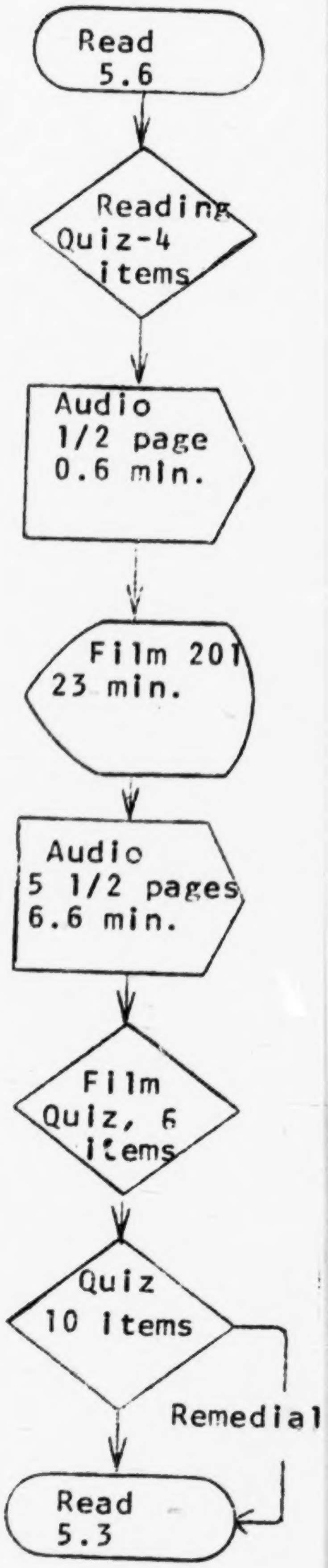
ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Define mass.

Given changes in characteristics of a gas with other characteristics held constant, what will happen? (Student is expected to be able to work with the Ideal Gas Law).



Lesson Number: 6
Lesson Title: Introduction to Light and Optics



OBJECTIVE:

Introduction to light and optical phenomena.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Vectors and vector algebra--a vector is a quantity having both magnitude and direction. Familiarity with vector addition.

CONCEPTS TO BE ACQUIRED:

Light travels in straight lines.

Four ways in which light may be bent:

1. reflection--light reflected from a plane surface will have equal angles of incidence and reflection;
2. refraction--light traveling through two transmitting media will experience a change in the path according to Snell's Law $\sin i/\sin r = n_r/n_i$;
3. scattering--reflecting or refracting light so as to diffuse it in many directions;
4. diffraction--modification that light undergoes when passing the edge of an opaque body.

Properties of light and optical phenomena:

1. images--visual counterpart of an object formed by a mirror or lens;
2. real images--light rays appear to converge at the image; image may be detected on an opaque surface;
3. virtual image--no light rays actually pass through or originate at the image;
4. inverted and perverted images--
   perverted--right and left sides of image interchanged;
   inverted--top and bottom of image are interchanged.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

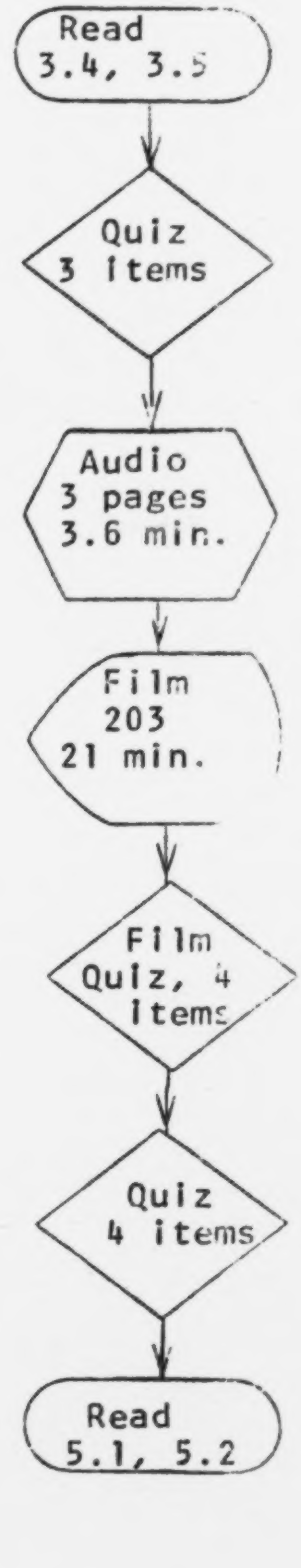
What is the relationship between the angle of incidence and the angle of reflection for light reflected from a plane surface? (They are equal.)

What are the characteristics of the two basic types of images? (real and virtual)

What are the describing characteristics of inverted and perverted images?

Describe four ways in which light can be "bent".

Lesson Number: 7
Lesson Title: Particle Model of Light



OBJECTIVE:

Given general characteristics of light (lesson 6), this lesson suggests a model for use in later work. The model suggested at this time is the particle model.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Light travels in straight lines.

Definition of reflection--light is reflected from a plane reflecting surface with the angle of reflection equal to the angle of incidence.

Definition of refraction (Snell's Law)--when light, traveling through a transmitting medium strikes the surface of another transmitting medium the path of the light bends toward (or away from) the normal to the interface according to the relationship $\frac{\sin i}{\sin r} = \frac{n_r}{n_i}$

CONCEPTS TO BE ACQUIRED:

Characteristics of light which can be explained by the particle model:

a. light travels in straight lines.
b. reflection
c. refraction
d. intensity of illumination--more particles striking a unit surface in a unit of time yield a higher intensity of illumination.

Possible failure of model: speed of light in two media; does light travel faster in water than in air? Particle model says water. (Snell's Law derived using velocity vectors.)

Properties of particle model: 1) light consists of particles where the source intensity is proportional to the number of particles per second; 2) the particles are small so light won't scatter in clear air; 3) particles travel very fast so that gravity won't affect their path.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

What are the basic properties of the particle model?

According to the particle model, does light travel faster in water or in air? (water.) How is this predicted by Snell's Law?

$$\frac{\sin i}{\sin r} = \frac{v_r}{v_i}$$

What does experimentation show us concerning this relationship of velocities? (Light is faster in air.)

Lesson Number: 8
Lesson Title: Failure of Particle Model of Light and Introduction to Wave Model

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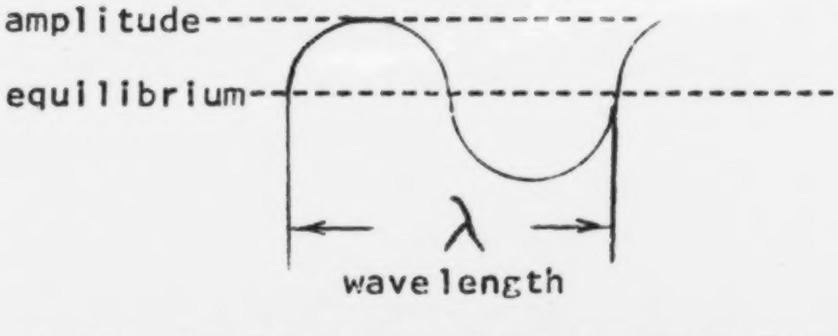
OBJECTIVE:

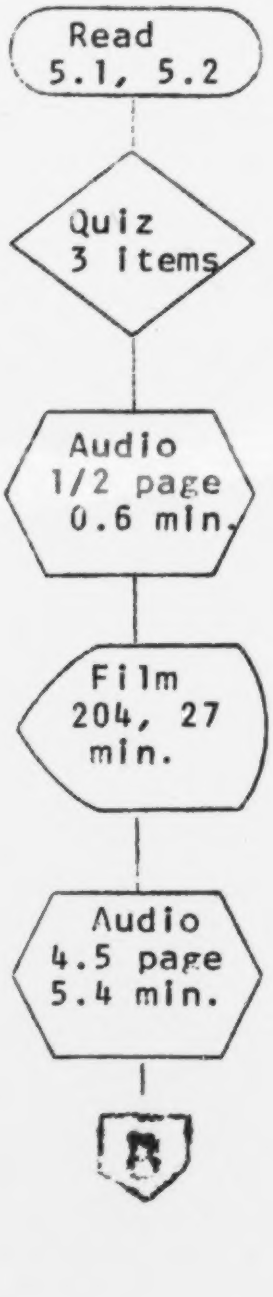
Enumerate failures of particle model for predicting Snell's Law of refraction which states that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant and equal to the ratio of the incident wavelength to the refracted wave length.

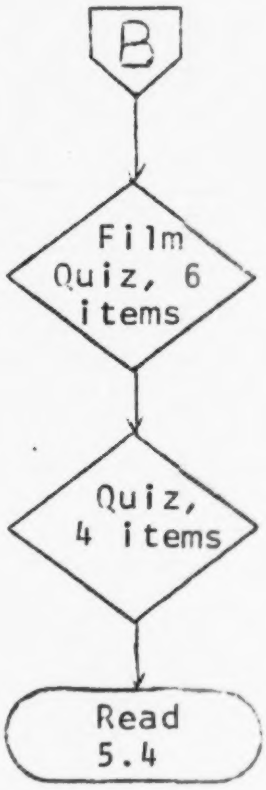
Particle model erroneously predicts that light moves faster in water than in air.

Introduction of wave model. Newton was dissatisfied with the particle model and subsequently suggested that light may be a series of periodic sine waves defined by the following diagrams:



If the equilibrium axis becomes a time scale, frequency of wave vibrations may be specified as the number of wavelengths in one time unit. The period of vibration is defined as reciprocal of the frequency, or length of time for passage of one complete wave.

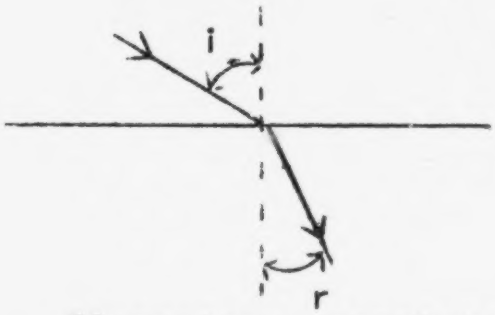




CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Particle model of light--light is defined to be a series of small particles traveling in straight lines.

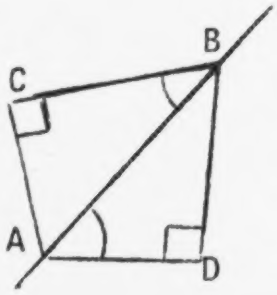
Snell's Law:



$$\frac{\sin i}{\sin r} = \text{constant}$$

Elementary geometry--(a knowledge of similar triangles) Student must follow proof that!

$$\frac{CA}{\sin r} = \frac{BD}{\sin i}$$



Reflection--a ray of light is reflected from a plane reflecting surface with the angle of reflection equal to the angle of incidence.

Refraction--with few exceptions, light velocity in a material surface is different from that in free space.

CONCEPTS TO BE ACQUIRED:

Reflection of waves--a plane wave is reflected from a plane surface with the angle of reflection equal to the angle of incidence (law of reflection).

Behavior of waves in one medium--wave length and velocity are constant.

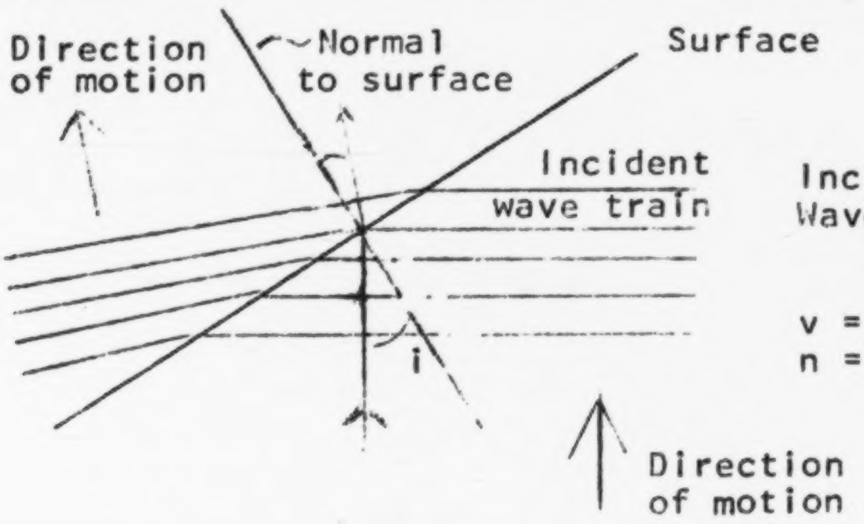
Refraction of waves--when a train of light waves, traveling in a transparent medium, strikes the surface of a second different transparent medium, two new wave trains are found to be originated at the interface. The reflected wave travels back into the first medium according to the law of reflection. The refracted wave propagates through the second medium in a direction predicted by the index of refraction of the second medium.

Wavelength --distance between successive crests or successive troughs in a wave train.

Wave velocity--product of the wave frequency and the wavelength.

Wave frequency--number of vibrations in a unit of time.

Period of a wave--time required for one complete vibration.
Derivation of Snell's Law using wave model of light.


Direction of motion
Normal to surface
Surface
Incident wave train
i
Direction of motion

Incident Wave Train $\frac{\sin i}{\sin r} = \frac{v_i}{v_r} = \frac{n_r}{n_i}$

v = velocity
n = index of refraction

Refracted Wave Train.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Describe a wave train and its important components and characteristics.

What is unsatisfactory about the particle model? (Fails to correctly predict speed of light in water.)

Lesson Number: 9
Lesson Title: Wave Model of Light

OBJECTIVE:

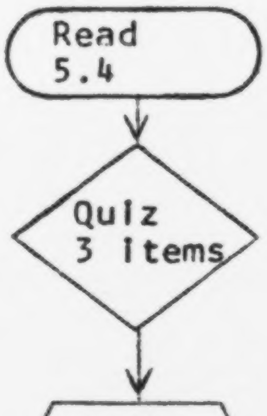
Introduce advantages and characteristics of wave model.

Diffraction of waves--light may be observed to bend around objects and produce secondary shadows which differ from the geometrical shadow suggested by particle model of light.

Principle of superposition--when two waves cross in a medium, the net displacement of the medium from equilibrium at that point is the sum of the two individual displacements.

Constructive interference--two or more waves cross in a medium to produce a larger resultant wave.

Destructive interference--two or more waves cross in a medium to produce a smaller resultant wave.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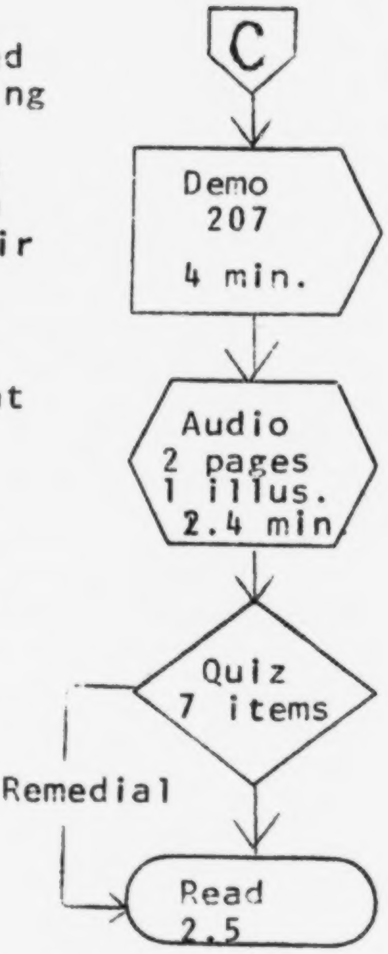
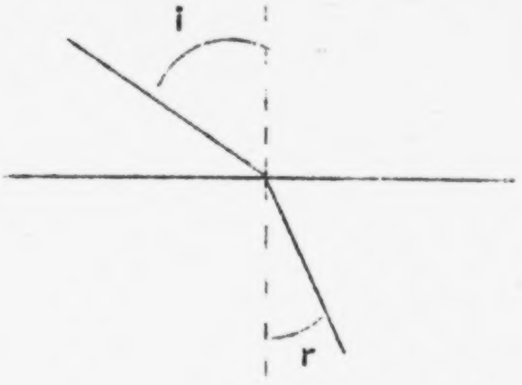


CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

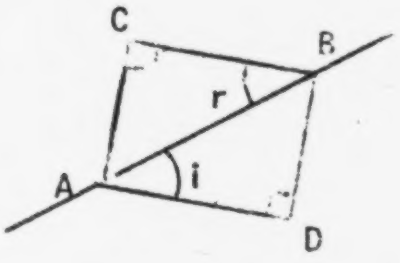
Particle model of light--light defined to be a series of small particles traveling in straight lines.

Snell's Law--discovery that the sines of the angles of incidence and refraction stand in a constant ratio for a given pair of media.



$$\frac{\sin i}{\sin r} = \text{constant}$$

Elementary geometry--(knowledge of similar triangles) Student must follow proof that:



$$\frac{\overline{CA}}{\sin r} = \frac{\overline{BD}}{\sin i}$$

Reflection of waves--a plane wave is reflected from a plane surface with the angle of reflection equal to the angle of incidence (law of reflection).

Behavior of waves in one medium--wavelength and velocity are constant.

Refraction of waves--when a train of light waves, traveling in a transmitting medium, strikes the surface of a second, different transmitting medium, two new wave trains are found to be originated at the interface. The reflected wave travels back into the first medium according to the law of reflection. The refracted wave propagates through the second medium in a direction predicted by the index of refraction of the second medium.

Wavelength.--distance between successive crests or successive troughs in a wave train.

Wave frequency--number of vibrations in a unit of time.

Period of a wave--time required for one complete vibration.

CONCEPTS TO BE ACQUIRED:

Characteristics of wave optics:

1. wave model of light--in order to explain interference and diffraction, the thought is projected that light may be some type of wave motion.
2. diffraction of waves.
3. principle of superposition
   a. constructive interference
   b. destructive interference
4. principle of non-reflecting glass--thickness of glass regulated so that green light (average wave length 5.3 x 10^{-7} meters) is totally absorbed by the glass.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Explain and define diffraction and interference. (see above)

Does the wave model agree with experimental results concerning the speed of light in water and air? (yes)

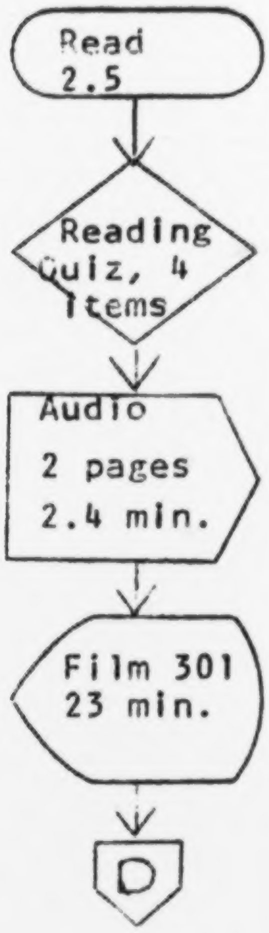
Lesson Number: 10
Lesson Title: Forces

OBJECTIVE:

Introduce the concept of a force--an influence that causes motion or a change in motion.

Enumerate three basic types of forces --gravitational, electromagnetic and nuclear.

Demonstrate that gravitational forces are smallest--a film illustrates Cavendish's experiment showing gravitational attraction between two masses.



CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Definition of a vector--quantity having both magnitude and direction.

Basic vector algebra--addition of vector, see lesson 4.

CONCEPTS TO BE ACQUIRED:

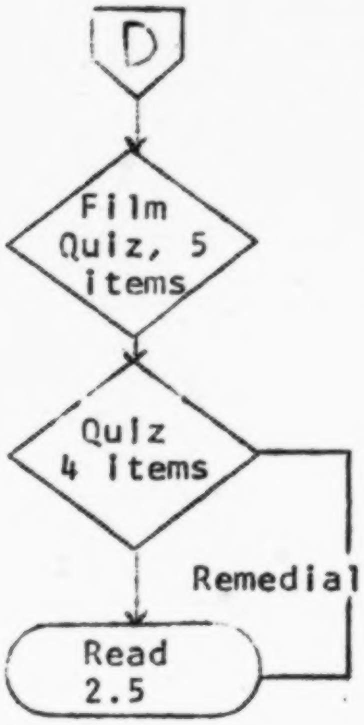
Definition of a force--an influence that causes motion or a change in motion.

Effects of forces--demonstrated in film 301.

Vector representation of a force--forces are vector quantities.

Universality of gravitational attraction--demonstration of gravitational forces ($F = G\frac{m_1 m_2}{d^2}$) by means of the Cavendish experiment (measurement of gravitational force between two masses). Conclusion : gravitational forces are not restricted to large celestial bodies.

Definition of acceleration--time rate of change of velocity.



ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Define a force. (If a body is observed to change its path of motion, what has happened? It has been influenced by a force.)

Give an example of three basic types of forces: (gravitational, electromagnetic and nuclear).

Which of the three basic types is the weakest? (gravitational)

Define acceleration. (time rate of change of velocity; it is a vector.)

Lesson Number: 11
Lesson Title: Newton's Law and Inertia

OBJECTIVE:

Show that a force is necessary to overcome inertia and change the motion of a body. (film 302)

Define Newton's second law of motion. ($\vec{F} = M\vec{A} = M\frac{\Delta\vec{v}}{\Delta t}$)

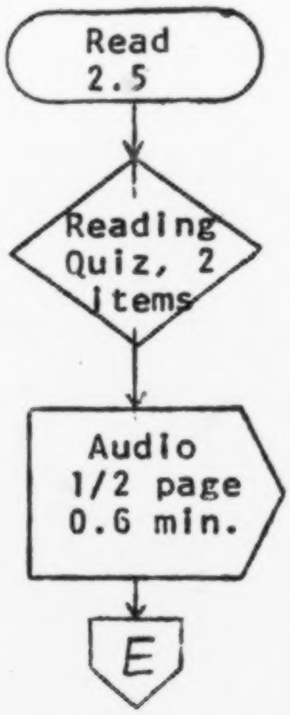
Define and demonstrate the vector nature of forces. (The result of applying several forces to a body may be characterized by the vector sum of the forces.)

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Functional relationships (direct and inverse proportion).

Familiarity with vectors. (See lesson 4)

Definition of a force. (An influence that causes motion or a change in motion.)



CONCEPTS TO BE ACQUIRED:

Forces (Body moves in a straight line if there are no unbalanced forces acting on it. A body changes velocity if a force is applied to it.)

For the same object: Acceleration is proportional to force ($a \propto F$).

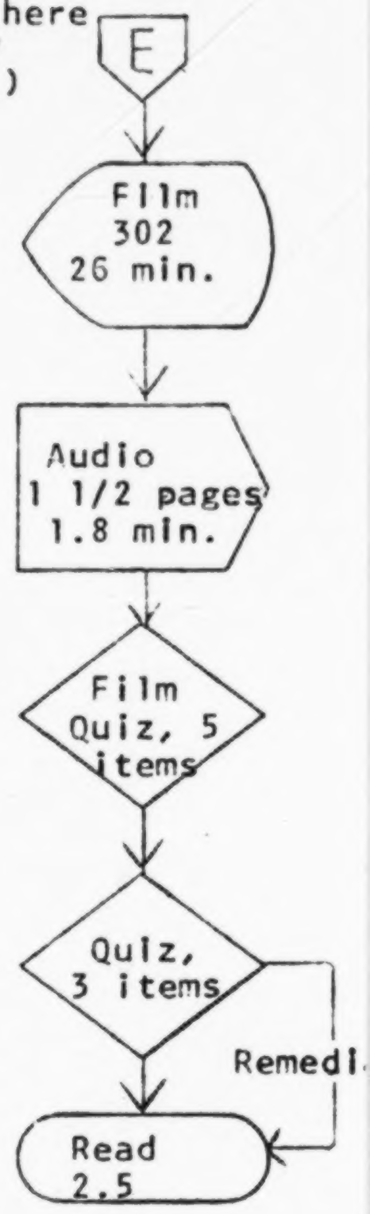
For the same force: Acceleration is inversely proportional to mass ($m \propto \frac{1}{a}$).

Vector nature of force, acceleration and velocity--all three quantities are vectors and must be treated algebraically as vectors.

Quantitative expression for Newton's second law of motion ($F = ma$, $F = m\Delta v/\Delta t$)

Definition of inertial mass--initially, force and inertial mass are used synonymously where inertial mass is the constant which changes the above proportionalities to equalities.

Units of force. (one newton equals one kilogram meter per second per second.)



ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

What happens when two different bodies are acted upon by the same force? (They experience accelerations proportional to their masses.)

How may one measure the inertial mass of a body? (Set the body in motion under the influence of a constant force and observe the time rate of change of the velocity.)

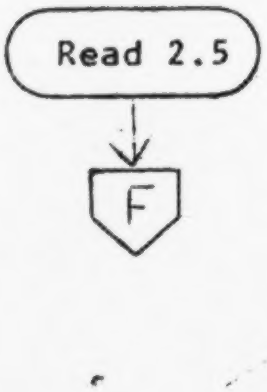
Define inertial mass. (That quantity which is the ratio of a given force to the acceleration it produces.)

Lesson Number: 12
Lesson Title: Weight and Mass

OBJECTIVE:

Show that weight and mass are not the same. (Demonstrate that weight is a force which may be attributed to the acceleration due to gravity; mass is a universal unchanging property of a body.)

Define acceleration due to gravity. (Acceleration of gravitational attraction to the center of the earth.)



CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Definition of a force--an influence which causes motion or a change in motion.

Familiarity with Newton's second law of motion. (See lesson 11, $\vec{F} = m\vec{a}$)

CONCEPTS TO BE ACQUIRED:

Definition of weight--mass of an object multiplied by the acceleration due to gravity. ($\vec{W} = m\vec{g}$)

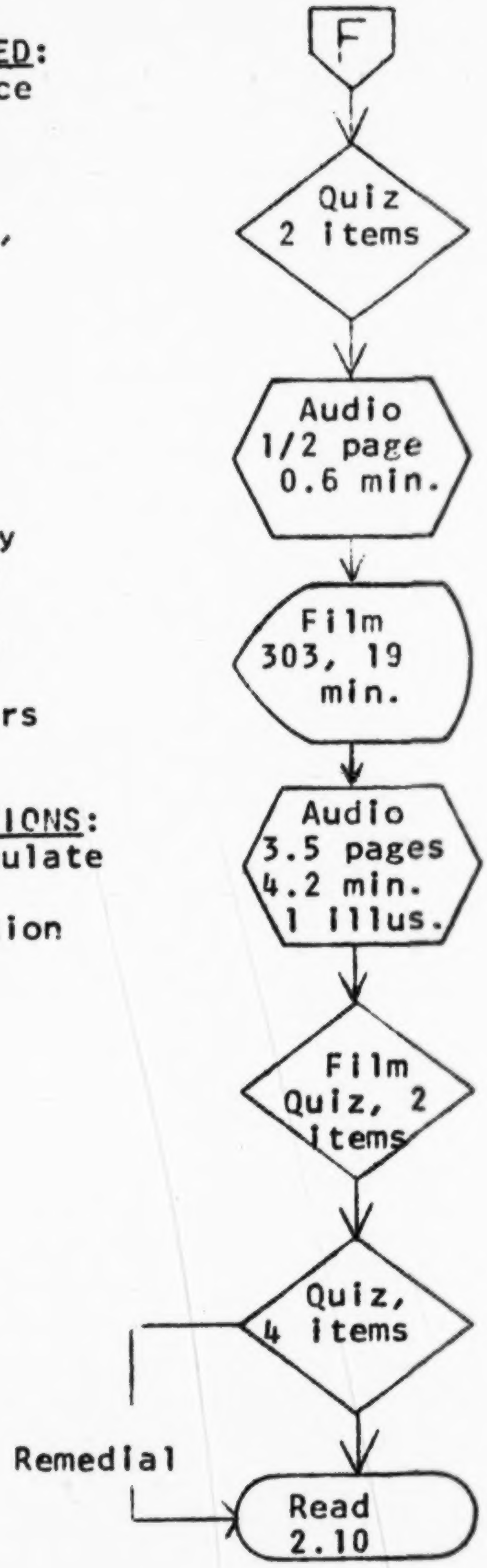
Definition of mass--universal property of a body that is measured by means of a beam balance with standard reference mass.

Definition of acceleration due to gravity--symbol "g" is employed to specify this acceleration of 9.8 meters per second per second.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Given the mass of an object, calculate its weight. ($\vec{W}$ = mg)

Define mass, weight and acceleration due to gravity.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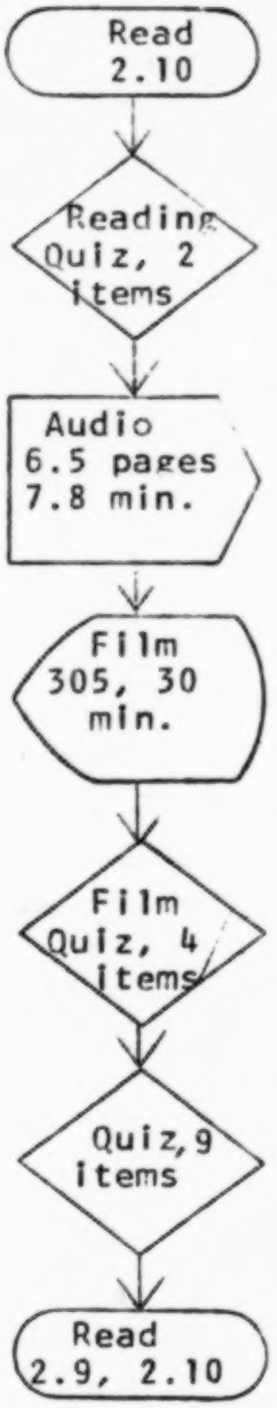
Lesson Number: 13
Lesson Title: Forces and Acceleration



OBJECTIVE:

Introduce deflecting forces--forces which cause a change in direction of motion.

Review Newton's second law--F = ma.

Introduce circular motion--motion resulting from a constant force continually applied at right angles to the direction of the motion.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Vectors (lesson 4).
Newton's second law (lesson 11).
Inertia (lesson 11).
Acceleration--time rate of change of velocity.

CONCEPTS TO BE ACQUIRED:

Nature of deflecting forces--(Newton's second law):

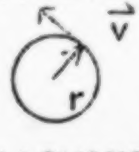
1. A deflecting force causes a change in direction of motion, not the speed.
2. If a body does not experience external forces, it will continue to move in a straight line.

Circular motion--constant deflecting force exerted at right angles to velocity will produce circular motion.

Velocity of circular motion given by $v = 2\pi r/t$.

Circular acceleration: $\vec{a} = 2\pi v/t$.

Centripetal force: $\vec{F} = m\vec{a}$ where a is circular acceleration. This is the force that causes the body to continually seek the center of the circular path.



ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Given a rotating mass traveling in a circular path of radius R and a period of rotation, T, calculate the force pulling the mass toward the center, the velocity, and the acceleration. ($v = 2\pi r/t$, $a = 2\pi v/t$, $F = ma$)

What forces act on bodies moving in a circular path? (One: centripetal force.)

What happens to a body moving in a circular path when the acceleration is reduced to zero? (The body follows a straight path in the direction of the velocity.)

Lesson Number: 14
Lesson Title: Satellites and Planets

OBJECTIVE:

Introduce principles of celestial mechanics--those principles which account for the feasibility of satellites.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Vectors (lesson 4).
Newton's second law (lesson 11).
Circular motion (lesson 13).

CONCEPTS TO BE ACQUIRED:

Principle which permits maintenance of orbital motion.

Centripetal force--force which draws rotating body toward the center of the circular path. Orbit achieved by adjusting velocity so that a satellite moves fast enough to always maintain circular motion.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

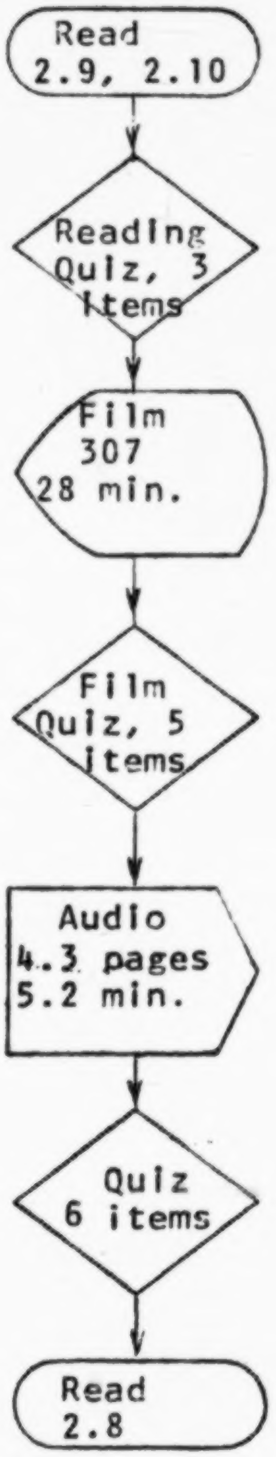
Given the altitude of a satellite orbit and the period of rotation, calculate the centripetal acceleration.*

Calculate the velocity necessary to achieve orbit at that altitude.*

What direction must the speed of a satellite take in order to maintain orbit? (tangent to orbit or perpendicular to radius vector of orbit)

What characteristic of the moon keeps it in the earth's orbit? (Its velocity)

*Use: $v = 2\pi r/T$ $a = 2\pi v/T$

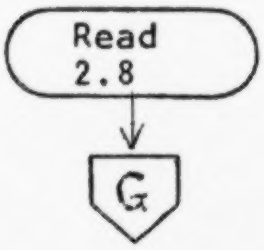


Lesson Number: 15
Lesson Title: Impulse and Momentum

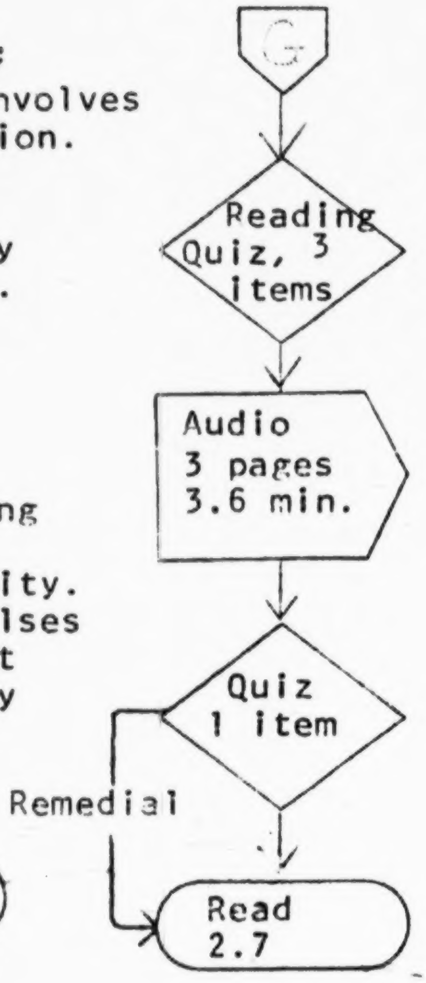
OBJECTIVE:

Introduce and define impulse: the product $F\Delta t$ where F is a force and Δt the time interval during which it is applied.

Momentum is a vector quantity.



Show that momentum is conserved in collisions--conservation of momentum law; momentum prior to collision (collision involves an impulse) equals momentum after collision.



CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Familiarity with concepts of velocity and mass--understanding of what they are.

Newton's second law of motion:

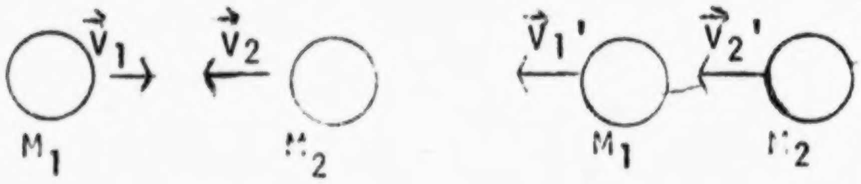
$$\vec{F} = \frac{m\Delta\vec{v}}{\Delta t}$$

CONCEPTS TO BE ACQUIRED:

Definition of an impulse--force acting for a fixed time interval, $i = F\Delta t$.

Momentum defined as mass times velocity.

Conservation of momentum--since impulses are equal and opposite, the momentum lost by one body equals the momentum gained by the second body.



Before Collision

After Collision
(new velocities identified by primes).

$$M_1\vec{V}_1 + M_2\vec{V}_2 = M_1\vec{V}_1' + M_2\vec{V}_2'$$

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Given that a force of magnitude, F, acts on a body of weight, w, moving at a velocity, v, what will the velocity of the body be if the force is discontinued after t seconds? (Use: $w = mg$, $F = m\Delta v/\Delta t$).

What is the momentum of the body before and after the influence of the force? ($p = mv$)

Questions involving conservation of momentum in which one of the quantities is unknown.

$$(M_1\vec{V}_1 + M_2\vec{V}_2 = M_1\vec{V}_1' + M_2\vec{V}_2')$$

Lesson Number: 16
Lesson Title: Introduction to Work and Energy

OBJECTIVE:

Introduce concept of work--the component of a force in the direction of motion, times the distance moved. The amount of work done on an object is equal to the energy gained by the object.

Introduce conservation of kinetic energy in elastic collisions--

$$1/2M_1V_1^2+1/2M_2V_2^2=1/2M_1V_1'^2+1/2M_2V_2'^2$$

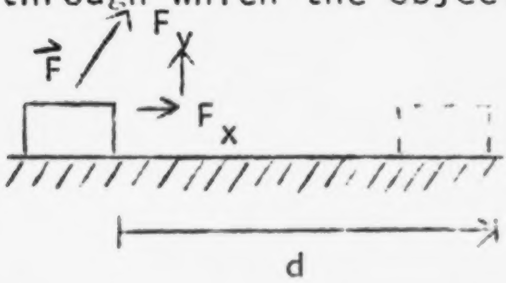
CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Definition of momentum--$p = mv$

Conservation of momentum--The total momentum of a system is constant:

$$M_1\vec{V}_1M_2\vec{V}_2 = M_1\vec{V}'_1+M_2\vec{V}'_2$$

Vector algebra--a resolution of a vector into its components. Work done is the product of the force component (parallel to the direction of the motion) and the distance through which the object is moved.



(Work done is $F_x d$)

CONCEPTS TO BE ACQUIRED:

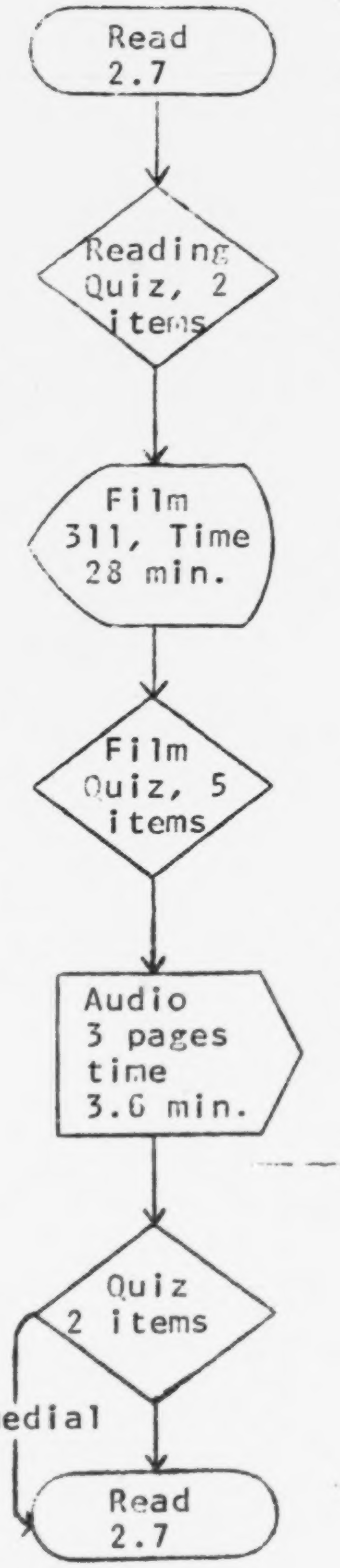
Definition of work--product of force component (parallel to direction of motion) and distance through which the object moves $W = Fd$.

Unit of work--newton-meter.

Relationship between work and energy--the amount of energy gained by an object equals the work done on the object which is shown to be $1/2mv^2$. This energy of motion is called kinetic energy. Unit is the joule; 1 joule = 1 newton-meter.

Conservation of kinetic energy--kinetic energy is conserved in elastic collisions.

$$1/2M_1V_1^2+1/2M_2V_2^2=1/2M_1V_1'^2+1/2M_2V_2'^2$$



ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Define work and units of measurement: $W = F_x d$, unit is newton-meter.

Define kinetic energy and its units.

Calculations, using conservation of momentum and conservation of energy in which one or two items are unknown.

Lesson Number: 17
Lesson Title: Potential Energy

OBJECTIVE:

Introduce and define potential energy--dormant energy stored in an object until it is caused to do work.

Concept of total energy--sum of potential energy and kinetic energy.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Kinetic energy--$1/2mv^2$

Conservation of kinetic energy--

$$\frac{M_1V_1{}^2}{2} + \frac{M_2V_2{}^2}{2} = \frac{M_1V_1'^2}{2} + \frac{M_2V_2'^2}{2}$$

Definition of work--work done is equal to energy gained. (In the case of a falling object, $mgd = 1/2mv^2$)

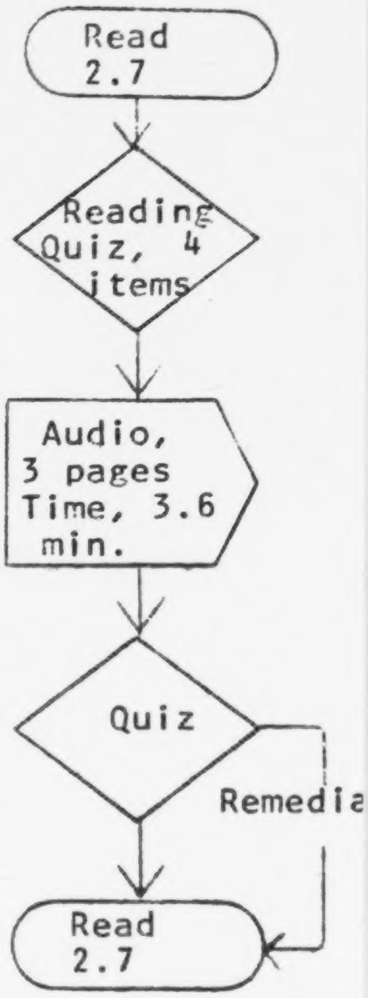
CONCEPTS TO BE ACQUIRED:

Conservation of total energy--kinetic energy gained is equal to potential energy lost. (In the case of a falling object, $mgd=1/2mv^2$)

Total energy--sum of potential and kinetic energy.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Calculations involving potential energy equation (P.E. = mgd) in falling object problems.



Lesson Number: 18
Lesson Title: Conservation of Energy

OBJECTIVE:

Demonstrate conservation of total energy --total energy in a system is conserved $PE_i + KE_i = PE_f + KE_f$. (Initial energy is equal to final energy.)

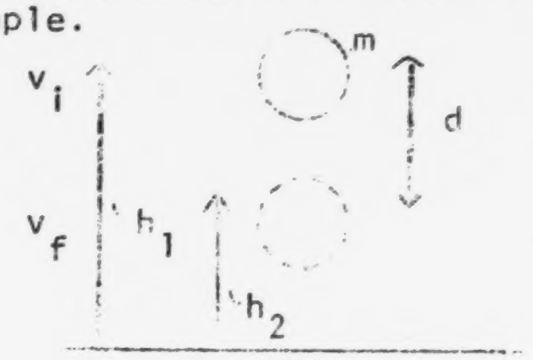
CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

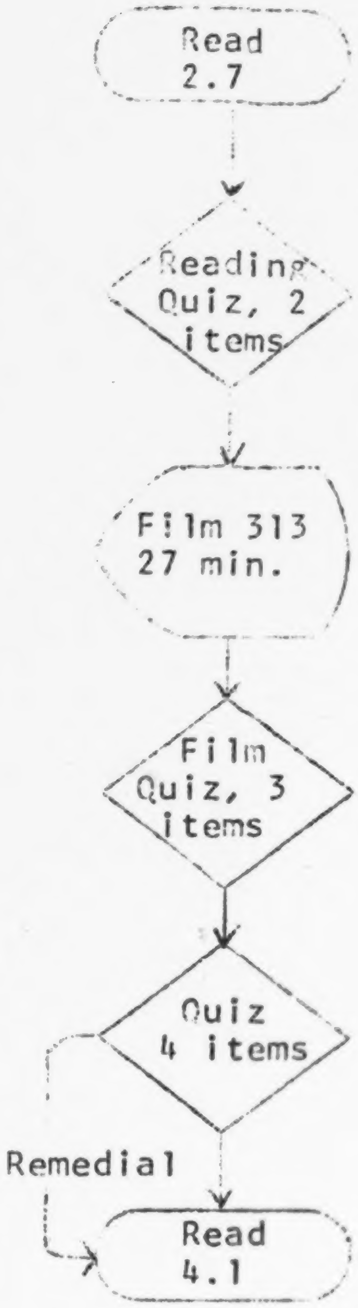
Definition of and familiarity with:
1. potential energy--stored energy
2. kinetic energy--$1/2mv^2$

CONCEPTS TO BE ACQUIRED:

Conservation of total energy.

Demonstration is with falling object example.





ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Given m, v_i, g, h_1, and d, what is v_f?

(use $\frac{mv_i^2}{2} + mgh_1 = \frac{mv_f^2}{2} + mgh_2$

What type of energy is always conserved? Total energy is conserved. However, potential energy may be converted to kinetic energy and vice versa.

Lesson Number: 19
Lesson Title: Introduction to Electrical Forces

OBJECTIVE:

Introduce forces due to electricity--most important force of three types discussed; more powerful than gravitational forces. Electric forces hold atoms together and are therefore quite important.

Define Coulomb's Law--a force between two charged particles is inversely proportional to the square of the distance between them.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Familiarity with effects of forces--cause motion or change in motion.

CONCEPTS TO BE ACQUIRED:

Coulomb's Law: $F \propto \frac{q_1 q_2}{d^2}$; q_1 and q_2 are indicators of the size or amount of charge.

Specify existence of two types of electrical charge.

1. rubbing silk on glass produces positive charges;
2. rubbing wool on rubber produces negative charges.

Specification of vector nature of the force: directed from center to center of the charged bodies, force is attractive for oppositely charged bodies; repulsive for bodies with like charges. Forces add vectorially and may have zero resultant, e.g., interior of charged, conducting sphere.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

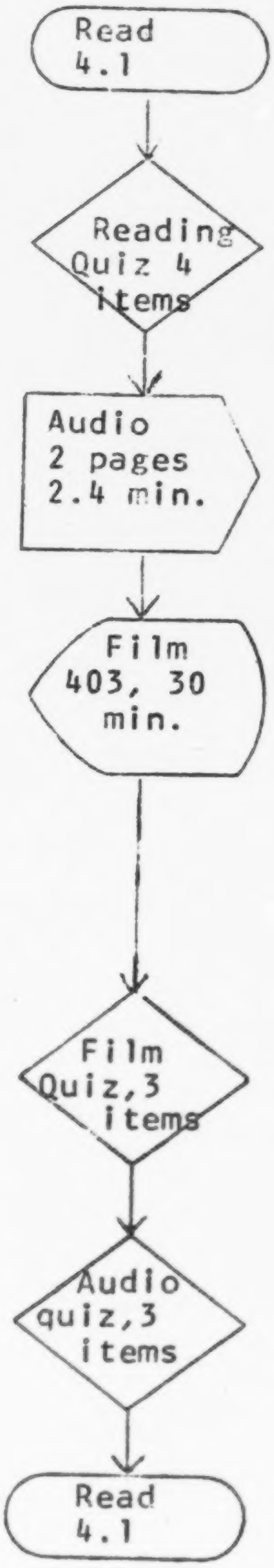
General questions involving characteristics of electrical forces as described by Coulomb's Law.

Is it a vector force?

What effect results from change in separation distance?

What effect results from change in quantity of charge?

When is force attractive? Repulsive?



Lesson Number: 20
Lesson Title: Coulomb's Law and Electrical Forces

OBJECTIVE:

Define electrical quantities--elementary charge (or "elem.chg.") (charge on 1 electron), conductors (charges free to move about), insulators (charges not free to move about), electrically neutral (same number of positive and negative charges), and net charge (total charge over entire object).

Define Coulomb's constant--constant which converts Coulomb's proportion to equality, $K = 2.306 \times 10^{-28}$ nt $m^2/(\text{elem. chg.})^2$.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Understanding of effects of electrical forces (lesson 19).

CONCEPTS TO BE ACQUIRED:

Definitions of electrical quantities. (see above)

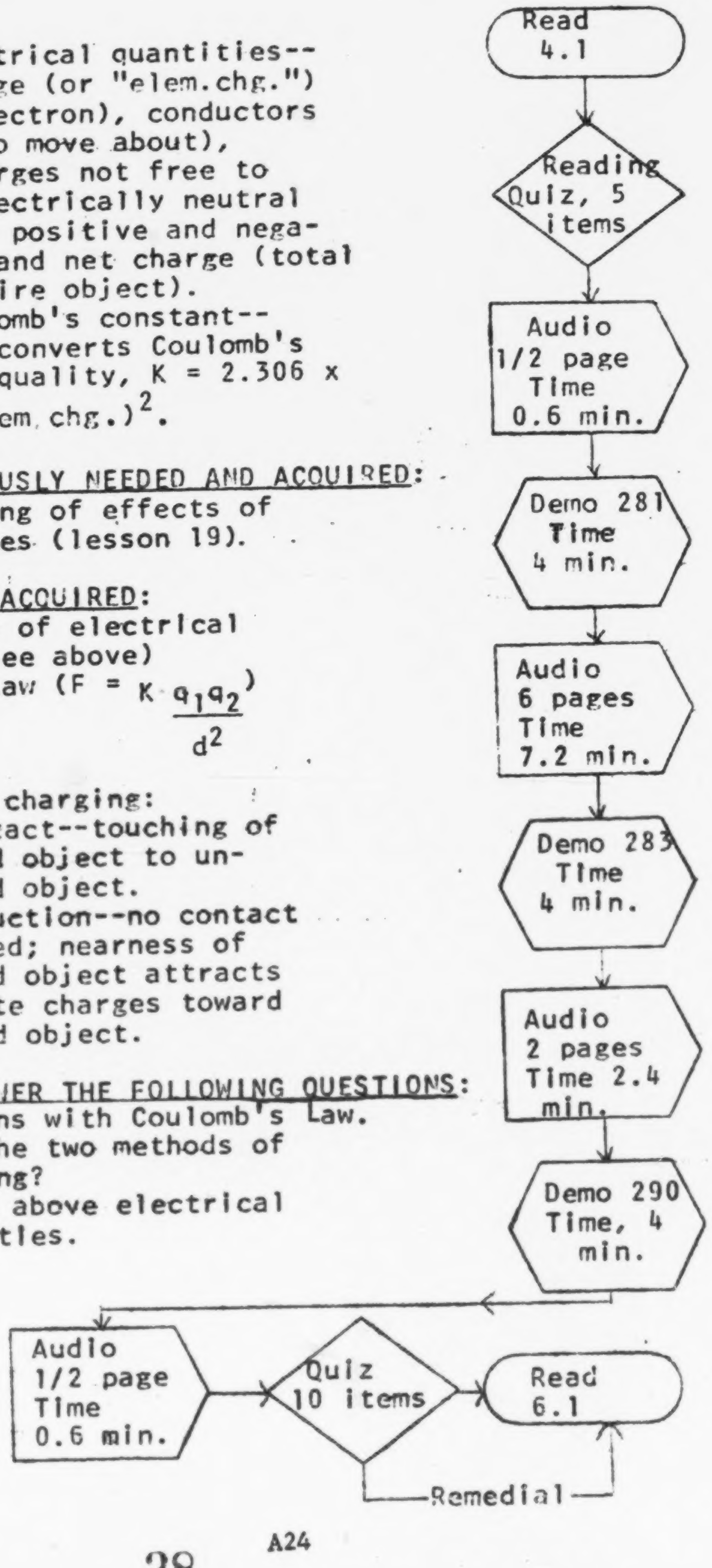
Coulomb's Law ($F = K \frac{q_1 q_2}{d^2}$)

Methods of charging:

1. By contact--touching of charged object to uncharged object.
2. By induction--no contact involved; nearness of charged object attracts opposite charges toward charged object.

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Calculations with Coulomb's Law.
What are the two methods of charging?
Define the above electrical quantities.


Read
4.1
Reading Quiz, 5 items
Audio
1/2 page
Time
0.6 min.
Demo 281
Time
4 min.
Audio
6 pages
Time
7.2 min.
Demo 283
Time
4 min.
Audio
2 pages
Time 2.4 min.
Demo 290
Time, 4 min.
Audio
1/2 page
Time
0.6 min.
Quiz
10 items
Read
6.1
Remedial

A24

Lesson Number: 21
Lesson Title: Elementary Charge and Electric Fields

OBJECTIVE:

Show application of Coulomb's Law to three body problems--three charged bodies exerting forces on each other.

Show calculation of the electric force in terms of force per unit charge and define it as the electric field strength.

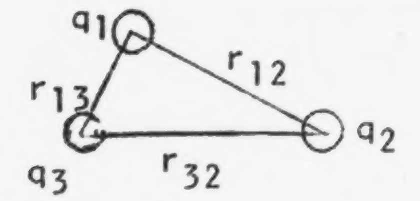
CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Coulomb's Law: $F_{12} = K \frac{q_1 q_2}{d^2}$ (subscript introduced to mean force exerted on charged body 1 by charged body 2.)

Vector algebra--addition of vectors to find resultant of components.

CONCEPTS TO BE ACQUIRED:

Coulomb's Law for three charged bodies--


q1
r12
r13
q2
q3
r32

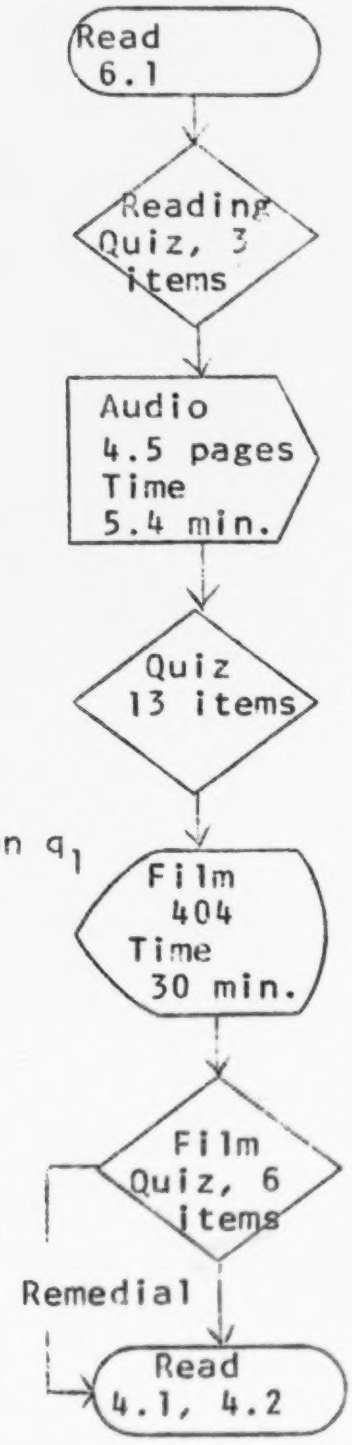
$\vec{F}_{12} + \vec{F}_{13} = \vec{F}$ net on q_1

Elementary electric charge--charge on one electron.

Calculations of force in terms of force per unit charge--called electric field strength. This quantity is found by dividing $\vec{F}$ by q_1 and, hence, determining a force that may be evaluated for q_1 of any size.

$$\vec{F}/q_1 = K \frac{q_2}{d_{12}^2} = \vec{E}$$

Define field as quantity whose effect is determined by an object's location in space. Illustrate a map of an electric field which is composed of the source of the field and electric lines of force (which indicate the direction and magnitude of E).

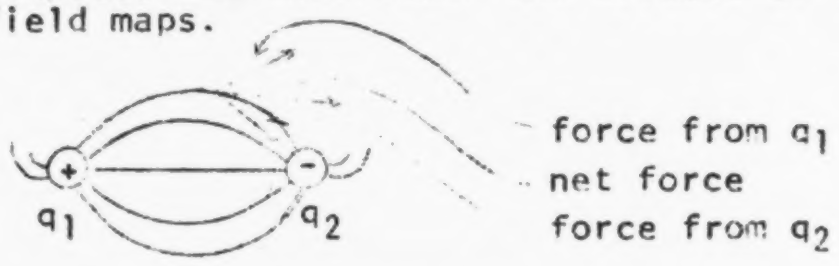

Read 6.1
Reading Quiz, 3 items
Audio 4.5 pages Time 5.4 min.
Quiz 13 items
Film 404 Time 30 min.
Film Quiz, 6 items
Remedial
Read 4.1, 4.2

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

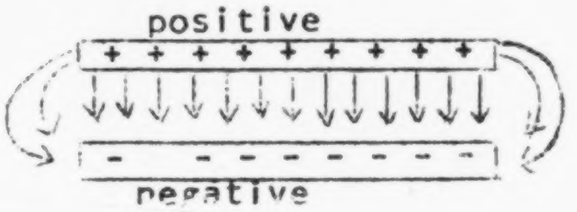
Calculations with Coulomb's Law involving systems of two and three body arrays. (Use $F = K \frac{q_i q_j}{(d_{ij})^2}$ and vector addition).

Student is expected to understand the effects of electric fields through field maps.

Two Point Charges



Two Parallel Plates



Define "elementary electric charge"--charge on one electron.

Lesson Number: 22
Lesson Title: Electric Energy

OBJECTIVE:

Introduce concept of energy gained by a charged particle when it is accelerated by an electric force.

Define electric potential--electric potential energy per unit charge.

Define electric current--symbol is "I" number of elementary charges passing a point per unit time.

Introduce electric circuits--the battery or generator referred to as an electric energy pump which provides energy to current elements.

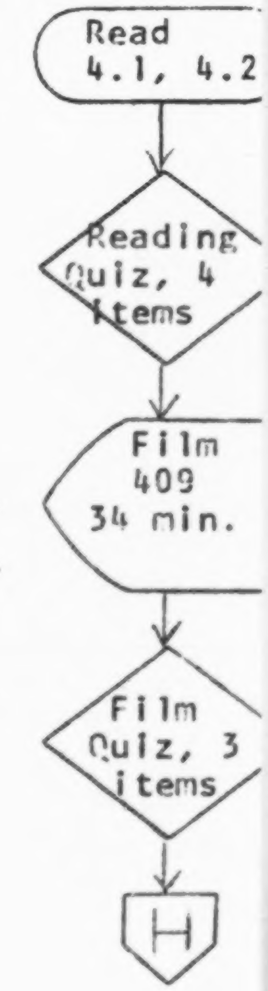
Ohm's Law--potential drop caused by resistance in circuit. Potential is proportional to current: $V = IR$.

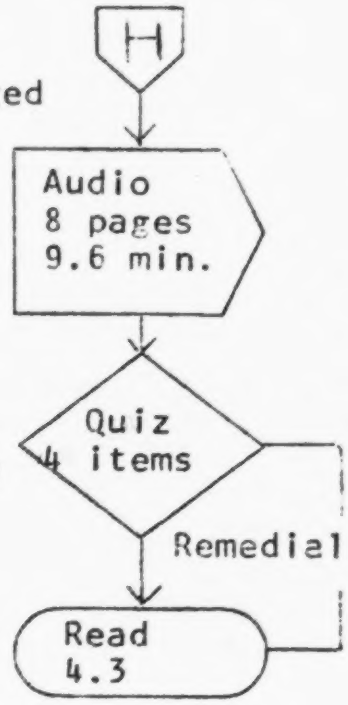
CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Work: the component of a force in the direction of motion times the distance moved.

Electric force--force per unit charge on an object known as electric field $E = F/q$. Charge makes the electric force act.

Potential energy--(symbol is "U") stored energy.





CONCEPTS TO BE ACQUIRED:

Electric work--electric force acting on a charged particle times the distance moved $W = Fd = qEd$

Electric potential energy per unit charge--called "electric potential"--$\frac{W}{q}=Ed=\frac{U}{q} = V$ Unit of measure is the volt. (joules per unit charge)

Ohm's Law--$V = IR$, V is potential difference, I is current, and R is resistance -- an alternate statement of energy conservation. Potential energy lost is equal to kinetic energy gained.

Electric energy sources--EMF or electromotive force is total potential supplied by battery or generator.

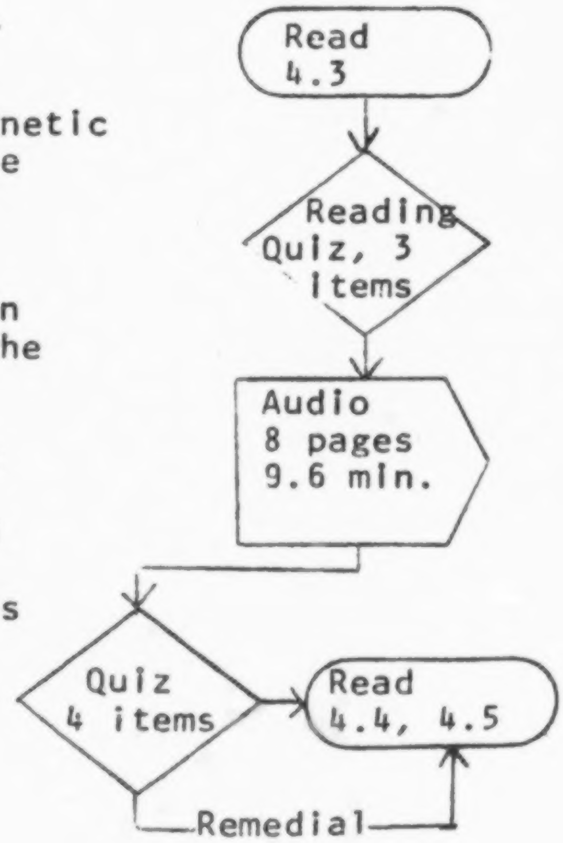
ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Calculations involving electric field and electric potential (use $E=F/q$, $\frac{W}{q} = Ed$, and $V = Ed = \frac{U}{q}$)

Calculations involving Ohm's Law (use $V= IR$).

Understanding of units of measurement associated with each of the above equations.

Lesson Number: 23
Lesson Title: Magnetism



OBJECTIVE:

Introduce and describe concept of magnetic forces--ferromagnetic meterials experience forces when in magnetic fields.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Fields--nature of force fields wherein lines of force represent the effects of the field.

Electricity--concepts of elementary charges, conductors, current and electric fields (see lessons 19-22).

Newton's Law--change in motion caused by force.

Current--plus charges moving from plus to minus.

Solids--crystalline substance with atoms fixed in arrays of a particular type.

CONCEPTS TO BE ACQUIRED:

Magnetic poles--north and south designations are used for defining existence of specific directions to magnetic forces.

Magnetic lines of force--magnetic forces exist in continuous closed loops.

Origin of magnetic field--fields are created by moving electrical charges (DC current and compass demonstration).

$F = qvB$ -- B is magnetic field.

Right hand rule--thumb of right hand pointing in direction of current, the fingers indicate direction of the magnetic field.

Magnetic fields exert forces on moving charges--the magnetic field causes a moving charge to move perpendicular to the field (2nd right hand rule--field current force)--principle of the electric motor.

Concept of permanent magnets -- current loops in ferrous materials produce magnetic fields.

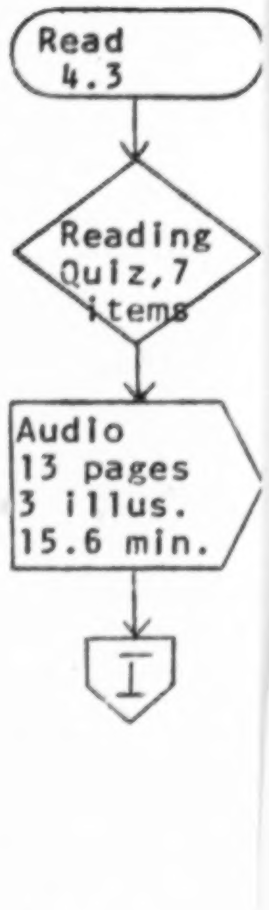
ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Understanding of right hand rule--given direction of current, what is the direction of the magnetic field?

Forces of attraction and repulsion are demonstrated by ___? (Like poles repel; unlike poles attract.)

What principle underlies the design of an electric motor? (Current, moving through magnetic field, experiences a force.)

Lesson Number: 24
Lesson Title: Induction



OBJECTIVE:

Induction--production of electric current by passing conductor through a magnetic field.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Work--force component times distance moved.

Magnetic force on moving charge--moving charge affected by magnetic field (See lecture 23).

Right hand rule--see lesson 23.

Electricity --concepts of electromotive force, current, conductor, elementary charge.

Field--see lesson 22.

Magnetic force-- $F = qvB$.

CONCEPTS TO BE ACQUIRED:

Wire moving through magnetic field causes electric current to flow in the wire--principle of an electric generator.

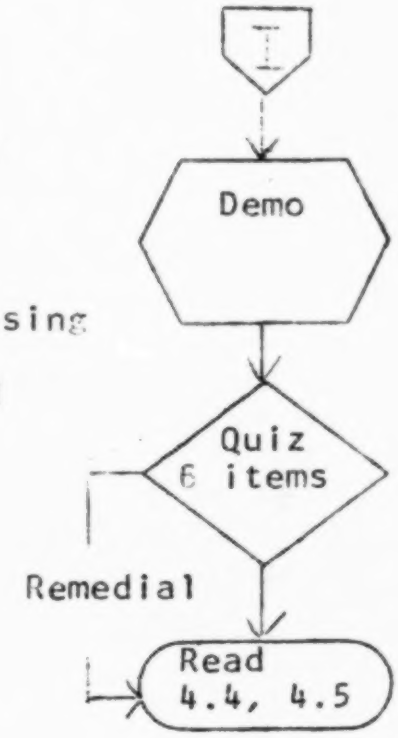
Electromagnetic induction--moving wire or conductor through magnetic field results in the flow of current. (Changing magnetic field exerts an electromotive force on elementary charges contained in the conductor.)

Changing magnetic fields set up electric fields. $E = \frac{\Delta \phi}{\Delta T}$

Magnetic flux--amount of magnetic field passing through an area A ($\phi = AB_{\perp}$)

Lenz's Law--$E = -\Delta \phi / \Delta T$, change in field will induce currents which tend to reduce that change.

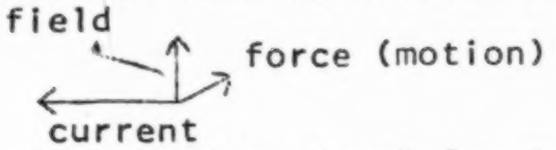
Lorenz force--$F = qvB$.



ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

What is the principle behind an electric generator? (Moving a conductor through a magnetic field causes current to flow in the conductor.)

Understanding of vector relationship of motion to field to current (right hand rule)



Calculations involving Lenz's law and Lorentz' forces.

Lesson Number: 25
Lesson Title: Electromagnetic Waves

OBJECTIVE:

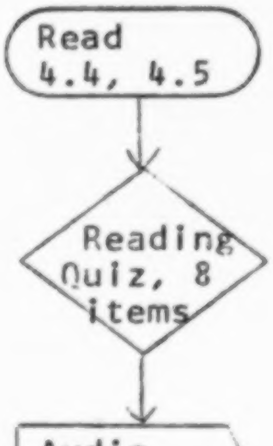
Introduce concept of the full electromagnetic spectrum of which visible light is but a small segment.

Point out examples of other parts of the electromagnetic spectrum (microwave, infrared, ultraviolet).

The concept of electromagnetic waves (all types) as pulsating magnetic and electric fields.

Introduce applications of EM fields as represented in radio antennas and broadcasting.

Introduce modern physics with a film: "Mass of the Electron," and point out the importance of the electron as a physical entity.



CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Electrical charges come in fundamental (or elementary)units.

Moving charges set up magnetic fields.

Magnetic fields exert forces on moving charges.

Changing magnetic fields set up electrical fields.

CONCEPTS TO BE ACQUIRED:

Recognition of the entire electromagnetic spectrum as encompassing waves of many energies and including the visible spectrum as one small segment.

The concept of an electromagnetic wave as a manifestation of a regularly pulsating electromagnetic field.

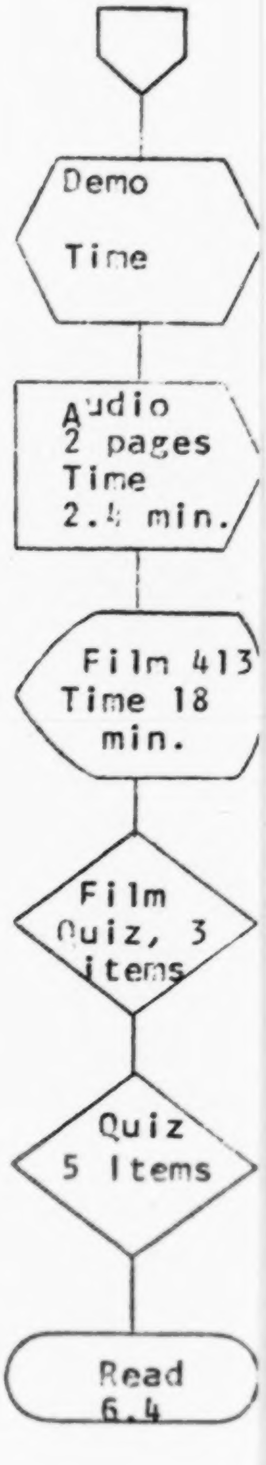
One way in which such a field can be set up: By causing a stream of charges to move regularly back and forth in an antenna.

Mass of one electron: 9.1×10^{-31} kg. Film 413 shows how the mass of an electron can be calculated.

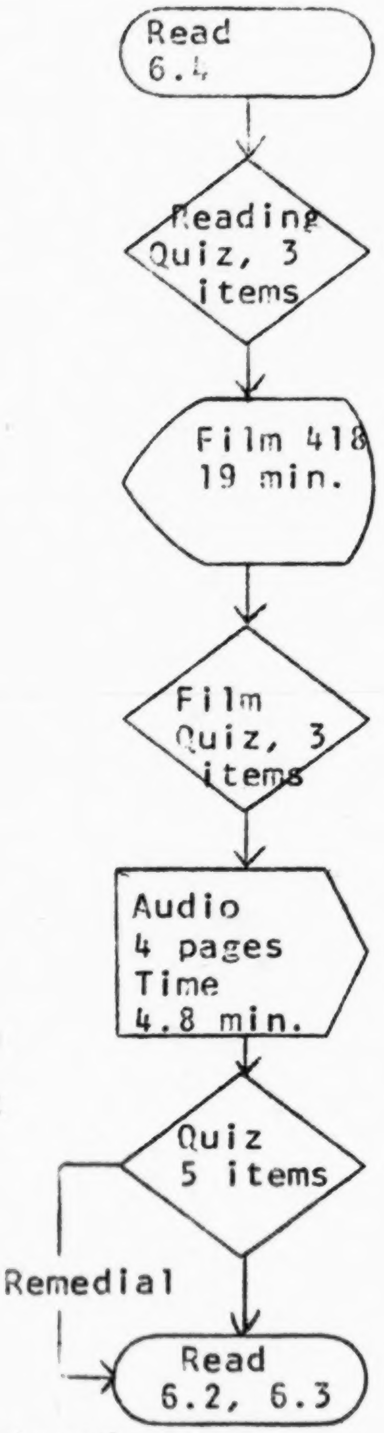
ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Give examples of four kinds of waves belonging to the electromagnetic spectrum: (microwaves, infrared, visible light, ultraviolet.)

How does a broadcasting antenna produce electromagnetic waves? (A stream of moving charges produces a magnetic field which changes as the charges change their direction of motion.



Lesson Number: 26
Lesson Title: Rutherford's Model of the Atom



OBJECTIVE:

How light interacts with matter. (As a particle.)

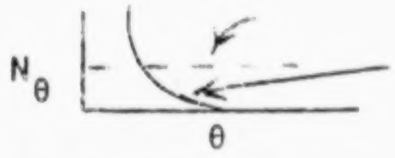
Early models of the atom--Rutherford and Thomson.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Atom--smallest unitary constituent of a chemical element.
Kinetic energy--see lesson 16.
Circular motion--see lesson 14.
Coulomb's Law--see lesson 20.

CONCEPTS TO BE ACQUIRED:

1. Terminology: atom, electron, proton, alpha particles, nucleus.
2. Thomson's "Raisin Pudding" model of an atom--Atom consists of large positive blob with negative particles embedded in it.
3. Rutherford's scattering experiment: Gold foil was bombarded with alpha particles. Thomson predicted uniform scattering, but the results were that most alphas were not scattered. Those that were deviated behaved as though repelled; a few were scattered straight back.



4. Rutherford's model of the atom--An atom consists mainly of empty space since most alpha particles are not scattered. Most are scattered, hence they come near the plus charge. Some are scattered straight back, hence plus charge is heavy. The plus charge is placed at the center (nucleus); electrons are placed in orbits around the nucleus. Coulomb's Law holds electrons in orbit.
5. Moving charges radiate electromagnetic energy.

A31

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Describe Thomson's model of the atom.

Describe Rutherford's scattering experiment.

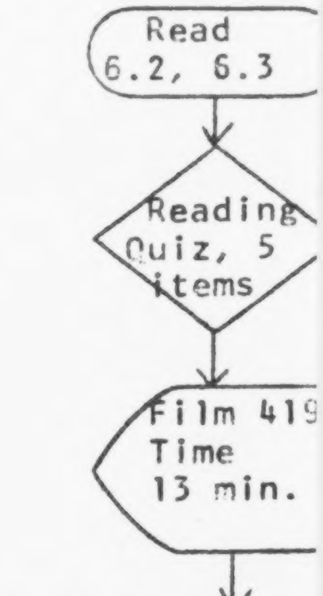
Describe Rutherford's model and give justification for his organization of components.

What holds Rutherford's model together? (Coulomb's Law.)

Calculations involving Coulomb's law on atomic scale. (Use $F = K q_1 q_2 / r^2$)

If moving charges radiate energy, why doesn't an atom collapse? (Classical theory predicts electrons would continually lose kinetic energy and soon spiral into the nucleus. Quantum physics explains why this does not happen.)

Lesson Number: 27
Lesson Title: Photons



OBJECTIVE:

Demonstrate dual nature of light--light behaves simultaneously as a wave and as a particle. The instrument of this is the photon.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Wave description of light--see lesson 8.

Understanding of particle nature of light --see lesson 6.

Electromagnetic radiation--Electrons in conductors are caused to become excited.

CONCEPTS TO BE ACQUIRED:

Definition of a photon--the fundamental unit in which electromagnetic radiation energy can be emitted or absorbed.

Nature of light--Light travels in discrete quanta called photons which demonstrate wave behavior. It is a vibrating electromagnetic field.

Light propagates as a wave; interacts
with matter as a particle.

De Broglie's Postulate--momentum of photons is inversely proportional to wave

Planck's Constant--energy of a photon. Planck's Constant times frequency ($E = hf$).

Blackbody radiation--a body which absorbs completely all of the radiation hitting it is called a black body.

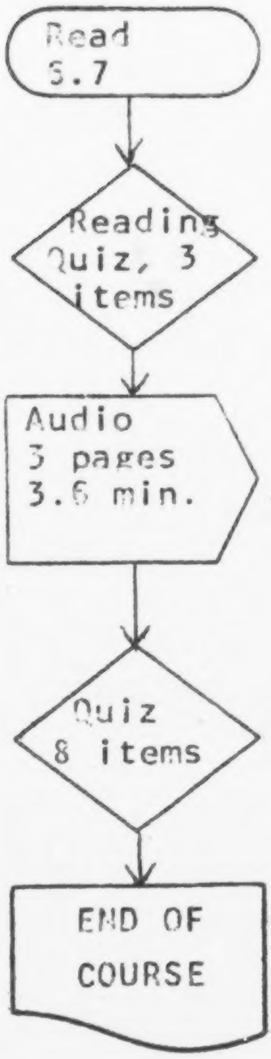
ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Describe a photon.

Describe the nature of light.

Calculations involving DeBroglie's postulate (use $E = hf$, $p = \frac{h}{\lambda}$).

Lesson Number: 29
Lesson Title: Atomic Physics



OBJECTIVE:

Conclude atomic physics--refinement of Bohr's model.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Bohr's Model of the atom--electrons travel around the nucleus in standing waves.

Balmer's formula--

$$f_{1n} = \frac{E_n - E_1}{h}, \quad E_n = \frac{-13.6}{n^2}$$

De Broglie's formula-- $\lambda_n = h/p_n$

CONCEPTS TO BE ACQUIRED:

Bohr's Postulates--

1. $\lambda_n = h/p_n$, $\lambda_n = h/mv_n$. Electrons exist in standing waves.
2. Circumference of orbit number ;
   $2\pi r_n = n\lambda_n = nh/mv_n$
3. Coulomb's Law holds atom together.
   $F = K \frac{q_{el} \; q_{pr}}{r^2_n}$. Force is also equal to centripetal force. $F = \frac{mv_n^2}{r_n}$

ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Calculations involving Bohr's postulates.

Lesson Number: 28
Lesson Title: Bohr Model of the Atom

OBJECTIVE:

Introduce to line spectra--characteristic frequencies of light emitted by atoms.

Franck-Hertz experiment--film, bombardment experiment to see if atoms may accept electron energy as internal energy gain.

Bohr Model of the atom--specifies that electrons may occupy several orbits of varying size.

CONCEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Discrete absorption and emission of light energy by atoms (see lesson 27).

Speed of wave: $v = \lambda f$

CONCEPTS TO BE ACQUIRED:

Balmer's line spectra--calculations of spectral lines characteristic of atoms:

$$f_n = \frac{E_n - E_1}{h} \qquad E_n = \frac{-13.6}{n^2}$$

Franck-Hertz experiment--showed that atoms can only accept energy in discrete steps.

Bohr model--predicts that changing of orbits by electrons produce spectral lines observed by experiment, changes in energy are equal to the product of a constant and the frequency of the spectral line.
$hf = E_1 - E_2$, $E = hf = \frac{hv}{\lambda}$

Standing waves--the concept that electron orbits are standing waves: $\lambda = h/p$ (known as De Broglie's Postulate.)

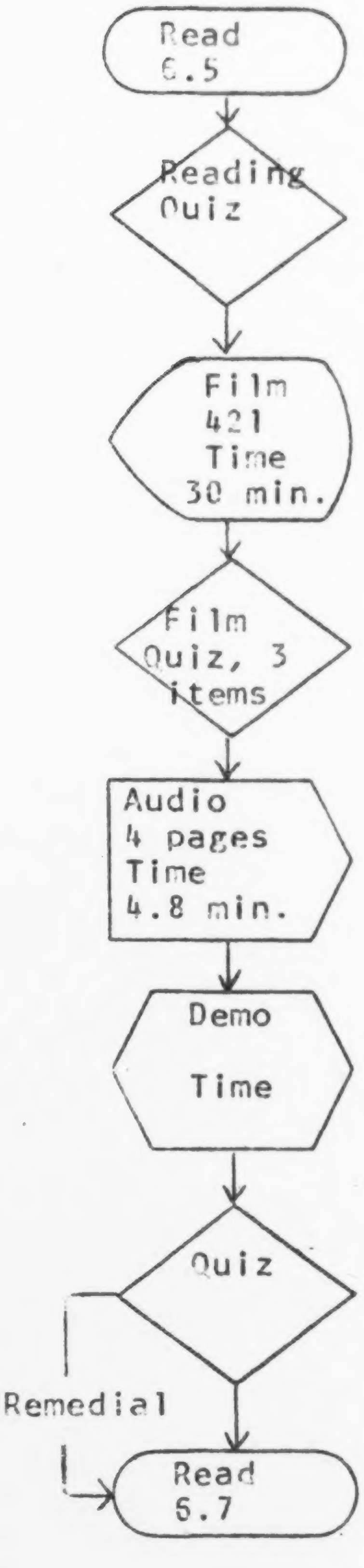
ABILITY TO ANSWER THE FOLLOWING QUESTIONS:

Calculations involving Balmer's line spectra: $f_n = \frac{E_n - E_1}{h}$, $E_n = \frac{-13.6}{n^2}$

Calculations involving the Bohr model: (use $hf = E_1 - E_2$, $E = hf = \frac{hv}{\lambda}$

Calculations involving standing electron waves:

$\lambda_n = h/p_n$. $2\pi r_n = n\lambda_n$ (quantization condition)



son Number: 29
son Title: Atomic Physics

ECTIVE:

Conclude atomic physics--refinement of r's model.

CEPTS PREVIOUSLY NEEDED AND ACQUIRED:

Bohr's Model of the atom--electrons travel und the nucleus in standing waves.

Balmer's formula--

$$f_{1n} = \frac{E_n - E_1}{h}, \quad E_n = \frac{-13.6}{n^2}$$

De Broglie's formula-- $\lambda_n = h/p_n$

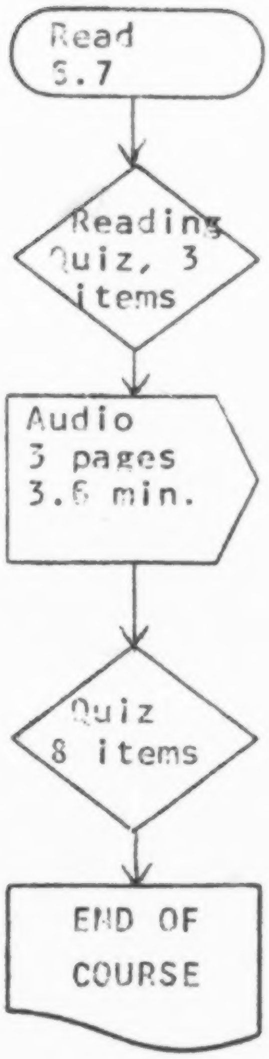
CEPTS TO BE ACQUIRED:

Bohr's Postulates--

1. $\lambda_n = h/p_n$, $\lambda_n = h/mv_n$. Electrons exist in standing waves.
2. Circumference of orbit number ;
   $2\pi r_n = n\lambda_n = nh/mv_n$
3. Coulomb's Law holds atom together.
   $F = K \frac{q_{el} \; q_{pr}}{r^2_n}$. Force is also equal to centripetal force. $F = \frac{mv_n^2}{r_n}$

LITY TO ANSWER THE FOLLOWING QUESTIONS:

Calculations involving Bohr's postulates.


Read
S.7
Reading Quiz, 3 items
Audio
3 pages
3.6 min.
Quiz
8 items
END OF
COURSE

INTRODUCTION

This document describes the Florida State University Data Management System (DMS) for dealing with response records generated by the IBM 1500/1800 Instructional Systems. Portions of the documentation are written with different types of readers in mind. Some portions deal with the overall idea and the concepts used in the development of the system. Others deal with programming concepts and operational details to run the programs on the system. Included also are examples of output generated for use by authors of educational materials.

The IBM 1500 Instructional System, in addition to its other functions, automatically records on magnetic tape the performance records from students. In an attempt to fulfill the requirement for analysis of this data, a program from IBM was provided with the capability of printing longitudinal student records. This program uses the technique of making repeated passes on the response tape, once for each student requested, and printing each valid record as it is encountered. Since one reel of tape is typically used for a single instructional session, it is difficult to get a continuous print-out for a single student across sessions. Furthermore, no capability is provided within this student performance listing program to list performance by item, across students. This latter type of information is, of course, more valuable than the former to the author of the course materials for purposes of making revisions in the course materials. An additional program was later included in the COURSEWRITER II package which took multiple session tapes and recorded them onto one tape. This was the so-called Performance Tape Agglomerator, which produces what are referred to as "PTA tapes." This combined session tape offers continuous student records across sessions but little or no additional capability for analyzing the responses in such a way as to provide summarized information for the author of course materials.

The program of research in Computer-Assisted Instruction (CAI) at Florida State University called for a much more extensive data management and data handling capability than was offered by these programs supplied by IBM. With this motivation, it was decided that a more generalized series of programs should be written in such a way as to handle the large files of responses generated by a CAI system. The information contained in the records could then be summarized and given to the authors of the CAI instructional materials. It is the purpose of the Florida State University Data Management System to perform these services.

The response record recorded by the 1500 system is a variable length record containing such items as the response itself, the latency, the contents and status of various record-keeping storage areas and an identifier for the response record. In order to maximize efficiency, these variable length records are first converted by the FSU Data Management System into condensed standard length records. Where necessary, continuation records are generated. These records are then sorted according to the course, the student, the record type (that is, whether it is a course header, a student header, or a response record), the date, the time of day, and whether it is a continuation record. The sorted records are then merged into a master file that constitutes the basic file with which the remainder of the programs work.

Next in the development of the Data Management System was the writing of what is called the Delete/Select program. In many ways, the uniqueness and power of this System resides in this program. It is through the use of the Delete/Select program that the author is able to obtain only that information which is relevant to answering questions regarding the data and not be overwhelmed with an unmanageable mass of data. It is also possible to specify output and analysis parameters so that the data is then available either as printed output in summarized records ready for the author to use, or as tape or punched records which then will be considered raw data for statistical analysis routines. At the present time, the set of programs to provide output in the form of raw data for use by statistical programs is still under development. It is very difficult, *a priori*, to anticipate possible needs for various different formats for this raw data. It is expected that as the system is used and data is analyzed and made available to authors, the evolutionary process will define new types of organizations of data and new ways of handling CAI data.

The reader interested in whether or not this Data Management System has usefulness for his operations should find this section, Section II (which requires basic knowledge of the 1500 COURSEWRITER II language), and the sample reports given at the end of Section VII most meaningful. Systems programmers and computer operators will also be interested in these same sections, but probably will be as much or more concerned with the remaining portions of the manual. The user of the CAI system and the designer of instructional materials will be most interested in this section, Section II, Section VI (the User's Manual), and Section VII

THE SYSTEM

THE SYSTEM

Concept and Design

The concept of a programming system for data management to be used with CAI was begun in late 1966 at FSU for use with the IBM 1440/1448 CAI System. This previous experience contributed toward the development of the present set of programs. The basic concepts and design were retained as they had been proved to be useful in previous use on the 1440 CAI System. The main differences are in the methods of selecting data from the master file and in the coupling of programs for statistical analysis of the data.

The design involved criteria which were used in guiding the organization of the DMS. These criteria were:

1. To organize and maintain large files of data as efficiently as possible.
2. To extract data from files based on any complex combination of completely variable data values and constants.
3. To efficiently resequence (sort) any file.
4. To develop a high degree of internal generalization so that the different programs could be operated as logical modules.
5. To implement, develop, and expand sets of standard and nonstandard statistical analysis routines and to provide a semiautomated interfacing of the data files with these routines.

6. To have the entire system monitored by program control, i.e., set up by control statements and regulated by stored parameter lists, so that in operation there would be a minimum of operator decision and intervention.

The system consists of four functional groupings of programs which perform file management, data retrieval, data analysis, and utility functions.

File Management

This function is that of a typical file maintenance application, i.e., raw input is edited and converted to a standard format, and then by sorting and merging, is updated into a master file. The steps in the operation are conversion and editing, sorting, and merging. Records which are incomplete or specially coded by a blank response identifier field (the EP Identifier) are not legitimate entries into the Data Management System and are therefore dropped in the conversion phase. This makes it the course author's responsibility to properly identify responses and allows for meaningless responses to be eliminated.

The sorting operation reorders the file in the "Master File Sequence" which is:

- Course Name
  - Student Number
    - Date
      - Time of Day
        - Continuation

This provides a file that is a chronological ordering of responses according to student within a course. The merge operation updates this master file with new data as it is received by the system. This file management function provides an updated master file which is used as input for all other activities. It constitutes a "data bank" at this point.

Data Retrieval

The usefulness of a data bank of the type provided is, in large part, a function of how easy one can extract that information which will help the user answer questions using the data collected.

Provision for this capability is by the Delete/Select program. This program allows the user to request that a new data work file be made from the master file, one which contains only the data requested. The request may be on the basis of any single or combination of items contained in the records themselves. The form of this request is similar to the FORTRAN IV "LOGICAL IF" statement and takes the form of: IF (condition(s) N), SELECT. The (condition(s) N) are specified by referring to data items and constants in the record and indicating their disposition by using a series of logical and relational operators. In effect, this allows the selection of data based on any combination of data parameters, identifiers, and parts of identifiers, switches, or counters, etc. Once a work file is available containing the desired information, the sort routine can then be recalled if desired to give any specified sequence. This work file, provided and sequenced by this data retrieval function, is then ready as raw data for input to the routines of the data analysis function.

Data Analysis

The data analysis function provides for various types of descriptive and inferential statistical analyses of the data in the work file. The output from this portion of the DMS can be printed summary records or can be in the form of raw data for input to statistical analysis routines. The printed, summarized data is illustrated in appendix G.

Initially, the IBM 1130 Statistical System (1130-CA-06X, Form H20-0341-1) has been converted for use on the 1800 computer. This package currently contains, stepwise linear regression and correlation, principal components and factor analysis with orthogonal and oblique rotations, analysis of variance for a factorial design, and least squares curve fitting by orthogonal polynomials.

Utility

This functional portion contains routines of a general utility nature which helps in the handling of the data files and assists in the development of additional capabilities. For example, they include routines which make sequence checks and counts, split tapes into sortable blocks if necessary, search for and locate end-of-file records, and dump tapes in hexadecimal. There are approximately eight separate programs in this functional portion of the DMS.

Implementation to Date

The file management and data retrieval functions are finished and operational. The data analysis function is partly operational. It is intentional that it remains open-ended so that the usefulness of the system is not fixed at some arbitrary state of development. The interfacing routines which automatically convert work tapes to acceptable input formats to other routines are currently under development. The DMS Monitor is partially implemented at this time.

It should be understood by the potential user of the DMS that continued enhancement of current programs is assumed and that development of additional capabilities will continue at Florida State University. In the next section, after the description of each program, are comments concerning various types of program improvement activities either planned or actually under way.

Additional capabilities that are currently under development include:

1. A different approach must be developed for efficient operation of the DMS Monitor due to the limitations that TSX imposes with respect to common subroutines controlled by LOCAL calls, in that they must be core resident at all times.
2. Routines for interfacing and automatically formating of data into the 1130 statistical programs and the "Stanford Analysis Routine."
3. A generalized punched card routine for providing a method of interfacing our data into data processing system programs where there is no tape capability or tape incompatibility.
4. Capability to edit the master file and therefore create an inactive file of data.

5. Generalized tape header label routines to automatically handle and identify all tape files.
6. Implement the DMS under the "Stanford Monitor."
7. Provide communication for operating instructions from the 1510 CRT and 1518 typewriter terminal devices.

User Participation

This system has been designed to provide a maximum of flexibility to the user in securing answers regarding his data. The users' operations staff should be responsible for the file maintenance function on an automatic cyclical basis while the user is responsible for originating requests for data and providing proper parameter information to successfully effect each request. (See User's Manual, Section VII.) The concept is to allow the user virtually complete freedom to independently explore the statistical implications of his data with the minimum of logistical interference due to computer operations or program restrictions.

USERS' MANUAL

The flexibility of the DMS generated the need for specific detailed reference so that the parameters required for each routine can be properly supplied. A form is provided to allow standardized communication with computer operations personnel (See Data Analysis Request Form, this section), and for them to carry a control on the request to its completion. A typical request will involve the extraction of specific data from the Master Data File; a resorting of the extracted data to a required sequence; merging sorted work files if necessary; and analyzing the final work file to produce output. The user should be completely familiar with the standard record format and be aware of the full potentials provided by the Delete/Select routine as well as the complete generality, with respect to sequencing, of the Sort and Merge routines. For analysis jobs which prove useful and for which multiple repetitions are anticipated, that job shall be defined as a monitor job so that all parameters and sequences of programs can be stored and the operation affected by a coded "call-down" monitor control card.

It is felt that the user should have some general insights into two specific aspects of the 1500 Instructional System and Data Management System so that he may better prepare his instructional materials in order to derive the maximum amount of meaningful data. With this in mind, comments are listed below which have proved useful and, in some cases, absolutely necessary for the successful collection of student response learning data.

The key to the author's ability to control the type of data which is collected lies in the identification of the various sections of the learning material (See raw response record format, appendix D). Since the essence of analyzing student response data is the capability of examining items of information in various contexts, particular attention must be paid to the efficient and logical preplanning of both the 'enter and process identifiers', (EPID) and the match identifiers.

EPID. This element of a response identifier is the identifier associated with a particular enter and process statement. It is important to note that it is the NEXT E.P. statement encountered which causes a recording to be made and that reflects the activity under the preceding E.P. statement. This means that after a response has been made and matched, the activity which you undertake on the switches and counters based on that match will be properly recorded.

In organizing your ten character E.P. identifiers, code them to have meaning with respect to your study. For example, questions within a pretest section could be identified thusly: PRE1, PRE2, . . . etc.,while a posttest might be POST1, POST2, . . . etc. In addition, reserving specific character positions (preferably the odd-numbered ones) which have intrinsic meaning with respect to that question has been useful. For example, the author can identify a remedial section, as differing from a testing section or a learning section, by the assignment of R, T, and L, respectively, to a particular character position within the EP identifier. Something such as this would allow him to embed and ultimately examine specific types of questions throughout an entire course without requiring that such questions be consecutively grouped together. By planning some logical unity to these identifiers that transcends the usefulness of a mere label you will be facilitating the application of computer search and retrieval techniques embodied in the Data Management System (DMS).

Blank EPID's have a unique designation in the DMS. Specifically , any response which is not associated with a defined EPID will not be included in the Master File. Thus, the author may delete from the file all unwanted responses by simply not labeling the associated EPID. Likewise, the author must label all EP's for which he wishes to record responses, i.e., responses to be included in the Master File MUST have non-blank EPID's.

The match identifier is potentially an extremely useful device. Since each position of the two position identifier can be any of 52 possible characters (numbers, alphabetic characters, special characters) more than 2700 combinations are possible. By judiciously selecting your coding structure for these identifiers, it is possible to carry the analysis of specific responses to great depth in an ordered fashion.

Efficient use of counters and switches will greatly ease your task of data collection. Some suggestions would be to accumulate latencies for specific sections; calculate means, etc.; use counters and switches to control branching, etc. Once a result has been placed in a counter for at least one response, that counter may be zeroed and reassigned for other use. The counter contents remain a part of the response record, for every response, therefore it would be necessary only to examine records that contain the desired counter contents rather than the entire file. The author can identify those records by causing selection based on his specific EPID's.

Counter zero can be addressed by the author. This is a dynamic counter that contains the latency for that response and provides the author with the capacity to perform latency calculations 'on-line' during course execution for each individual student. Since latency is stored in tenths of seconds, a counter can contain only sixteen minutes worth of latency time before the counter overflows.

A strong word of caution. Be extremely sensitive to the course execution logic with respect to 'in time' and 'timed out' conditions, and how this would affect counter manipulations. Uncautious course coding could invalidate much data collection preplanning.

The following action describes the general capabilities of the DMS. An understanding of the full capabilities of this system will facilitate data collection activities, and will provide the author with a maximumly effective means of data collection and reduction.

This section is intended to acquaint the user with the capabilities and the limitations of both the computer and some of the programs used in manipulating his data. This is done so that the user will be in a better position to communicate his needs and problems to the operator with a minimum of confusion.

The Computer

The main frame or central processing unit (CPU) which controls the activities of all the other units and does all of the internal processing of data is an IBM 1800 DATA ACQUISITION AND PROCESS CONTROL SYSTEM. The input/output units attached include a card reader for reading in programs and data stored on cards, a card punch for punching data in card form, a printer for communication with the operator and other printing requirements, two magnetic tape drives for storing large volumes of data and for recording student responses, three disk drives for storing course material on disk cartridges and for work space while manipulating data, and a 1502 data transmission control unit which handles all communication between the computer and the terminals. This complete system is called the IBM 1500 INSTRUCTIONAL SYSTEM.

The memory of the computer which is housed in the CPU consists of 32,767 words. Each word consists of 16 data bits which can contain a binary number ranging from -32,768 to +32,767 or two characters coded in Extended Binary Coded Decimal Interchange Code (EBCDIC). Each EBCDIC character occupies eight bits (called a byte) of the sixteen bit word. This feature of two characters per word is very important in manipulating the data because of certain restrictions it causes which will be explained later.

Delete/Select

The most useful program from the user's viewpoint will be the DELETE/SELECT program. This program gives the user the ability to select out only that response data that he needs for a particular purpose.

An example of the use of the routine might be in a course which the author has divided into three sections: a pretest, instructional material, and a posttest. If the counters are used simply to record the number of correct answers, the number of wrong answers, and cummulative response latency for each section, the author need only pick out the last response in each section for every student to gain the desired information. In this way the counters give him the same information that he would get from listing each and every response and adding them up manually.

There are several ways that a user may facilitate the selection of his data. One way is to make sure that he specifies his data requirements as complete and as concise as possible. Another way is for the user to write his own DELETE/SELECT parameters, since he knows his needs and his course better than the operator. (See WRITING DELETE/SELECT PARAMETER STATEMENT.) This avoids confusion in communicating your request to an operator.

The shorter and more concise the user can make his parameter statement, the faster the computer can handle his request. One shortcut that may be employed when specifying a string of variables such as student number is to make use of the less than or equal to and the greater than or equal to operators. I.e., to select student numbers S1 through S8, you can write it as:

```
('student'.eq.|S1|.or.|S2|.or.|S3|.or.|S4|.or.|S5|.or.|S6|
.or.|S7|.or.|S8|)
```

But a simpler way would be:

```
('STUDENT'.GE.|S1|).AND.('STUDENT'.LE.|S8|)
```

Another example would be:

Select from a course named COURS all responses from students K1 and K2 whose 5th character of the EPID is M. Also select all responses for students K3 and K4. The statement would be:

```
IF(('NAME'.EQ.|COURS|).AND((('STUDENT'.EQ.
|K1|.OR.|K2|).AND.('EP5'.EQ.|M|)).OR.
('STUDENT'.EQ.|K3|.OR.|K4|)))SELECT
```

Some points to remember when writing the statement are (1) never put two operands together without an operator between them, (2) never put two operators together regardless of whether it is one relational and one logical or two of one kind, without an operand between them, (3) no expression (See WRITING DELETE/ SELECT PARAMETER LIST for definition of terms) may contain more than one relational operator although it may contain several logical operators, and (4) always ensure that your parentheses are balanced and double check your logic to ensure that you get the data you are requesting.

WRITING DELETE/SELECT PARAMETER STATEMENT

General Description

The control statement may contain up to 400 separate operands including parenthesis, field identifiers, operators, and values. Control information is not included in this limit.

The parameter statement must begin with IF., e.g., IF ('NAME' .EQ. .... . The statement may begin in any card column and may occupy as many cards as necessary. To indicate that a statement is continued on another card, an asterisk (*) must be punched in a column following the last column used.

Imbedded blanks are allowed anywhere in the statement, but blanks cannot be used as a value to be compared against the record. Blanks in a value must be represented by # (3-8 punch).

Definitions

1. FIELD IDENTIFIERS - Refers to a field in the record
2. OPERATOR - The operation to be performed, either relational or logical
3. VALUE - The actual value to be compared to the field
4. EXPRESSION - A field identifier and one or more values connected by one or more operators and enclosed in parentheses, i.e., ('STUDENT' .EQ. |K1|.OR.|K2|)
5. STATEMENT - Two or more expressions joined by logical operators and enclosed in parenthesis, i.e.,(('NAME'.EQ. |P107|).AND. ('STUDENT'.EQ|S1|))
6. CONTROL INFORMATION - Tells the program whether to select or delete on the preceding parameters, which

pass to pick up, whether to accumulate latencies or not, and whether to accept originals only or all continuations.

Field Identifiers

Field identifiers must be enclosed in apostrophes. The following is a list of all valid field identifiers and the type of values that must be used with them:

Mnemonic	Definition	Type
'NAME'	Course Name	Alphanumeric
'STUDENT'	Student Number	Alphanumeric
'DATE'	Recording Date	Date
'EPID'	Response (EP) I. D.	Alphanumeric
	This compares the complete EP ID (10 characters)	
'EPID x'	One character of EPID . x = 1-10	Alphanumeric
'MATCH'	Match (WA, CA, etc.) I.D.	Alphanumeric
'MATCH x'	One character of Match I.D. x = 1 or 2	Alphanumeric
'LATENCY'	Response Time	Numeric
	NOTE: Latency is in 10ths of seconds	
'COUNTER x'	Any one of 30 Counters x = 1-30	Numeric
'SWITCH x ON'	Any one of 31 switches x = 1-31	Single Bit
'SWITCH x OFF'	Any one of 31 switches x = 1-31	Single Bit

Operators

There are two types of operators, relational and logical. Operators must be enclosed in periods.

There are six RELATIONAL operators. These are:

.LT.	Less than
.LE.	Less than or equal to
.EQ.	Equal to
.NE.	Not equal to
.GE.	Greater than or equal to
.GT.	Greater than

The three LOGICAL operators are:

.OR.	A or B true
.AND.	A and B true
.EOR.	A or B but not A and B true

Values

There are three types of values, alphanumeric (EBCDIC Code), numeric (BINARY), and date (Special Coding)

ALPHANUMERIC

Alphanumeric values must be delimited by a logical OR punch (12-7-8 or numeric Y punch) represented by a vertical line-example: |PSY2|.

To indicate a course name and segment number, a logical NOT punch (11-7-8 or numeric G punch), represented by ¬ should separate the course name and segment number. The segment number must be three digits. The entire value must be enclosed by logical OR's. Example: |PSY2 ¬ 001|

Numeric

Numeric values are delimited by @(8-4 punch). They may not contain more than five digits and the absolute value must not exceed 32767. Example: @300@

Note: Latency is recorded in tenths of seconds and any value to be compared to it must be in tenths of seconds also. i.e., for a latency of thirty seconds the value would be @300@. Please note the absence of decimal points.

Date

The date is stored in a special code and a value referring to date must follow the given format exactly. A logical NOT (11-7-8 or upper shift G), followed by six digits and another logical NOT punch.

The following is the format:

¬ YYMMDD ¬

where YY = Year

MM = Month

DD = Day

example: ¬ 680116 ¬ would be January 16, 1968

Control Information

The control information follows the last closing parenthesis in any order separated by commas. Parentheses in a statement must be balanced, otherwise an error will occur. Any option not chosen is simply omitted. No commas should be entered for missing options.

The following options are available:

Select	Select the records which match the parameter statement. (This option may be put on the card for clarification but it is not necessary as the program assumes select unless delete is specified).
Delete	Delete all records which match the parameter statement. (In essence, copy the tape leaving out the specified records).
X Pass	Consider only the X pass responses where X = 1^{st} - 9^{th}
Accumulate Latency	All overtime latencies are added to the next non-overtime record if it matches on date and EPID.
Originals	Do not keep continuation records. This would be used in analysis of data where counters and the actual response are not necessary.
Limit Tape	Limit tape to 15800 responses (for sorting purposes).

Examples

A parameter card may be as simple as:

```
IF ('NAME' .EQ. |ISCS1| ) SELECT
```

or it may be as complex as

```
IF ((('NAME'.EQ.|PSY2|) .AND. ('STUDENT' .GE. |S1 |) .AND.
('DATE' .LE. ¬ 680116 ¬ ) .AND. ('COUNTER 1' .EQ. @10@)
.AND. ('SWITCH 15 ON')) .OR. (('NAME'' .EQ. |ISCS1|) .AND.
('EP5' .EQ. |A| .OR. |B| .OR. |C |) .AND. ('LATENCY' .GE.
@100@ .AND. ('MATCH' .EQ. |CC|))) SELECT, 1stPASS, NON-
OVERTIME, ORIGINALS
```

Sort

To use the SCRT you need only specify on the job sheet the sequence in which you wish the data to be sorted. Keep in mind that if you have more than one segment and you specify course name and segment you will get all material for segment zero, then all material for segment one, and so on. So if you need the data for each student thru all segments you would have to take each student's responses from each segment and put them together again. In this case it would be much more convenient to specify course name without segment number. This would put all the material for each student through all segments together in linear form.

Because the 1800 word contains two EBCDIC coded characters, as mentioned previously, sorting on individual characters is not permitted in this machine. One way to get around this restriction is to ensure that the character that is to be sorted is in the first byte of the word. This is done by putting the control characters in the odd-numbered positions within a field. For example, if you want to control on two characters in the EPID, they would be characters one and three and you could sort on the first and second word of the EPID. This would put your data in order by the two control characters.

Data Analysis Request Form

This form is provided for the user to communicate his request to the system operator. A copy of the form properly filled out is attached and an explanation of it follows:

DATE REQUESTED: The date the request was given to the systems operator

REQUEST APPROVED: The request for path should be checked by the system operator supervisor to ensure that it is within the capabilities of the system and to ensure that it will fit into the schedule.

COURSE NAME (& SEGMENT # IF APPLICABLE): The name of the course as it was registered on the system. If data from all segments is required, segment numbers may be omitted. Otherwise, the numbers of the segments to be processed should be included.

INCLUSIVE DATES OF REQUESTED DATA: This should be the date that the first students became active to the date the last student finished. This information is used by the system operator to determine if your data is up-to-date within the DMS system and if not it helps him to find the data within the cycle.

APPROXIMATE NUMBER OF

RESPONSES: This figure is estimated by multiplying the number of students by the average number of hours per student and multiplying this figure by 240. This count is useful to the system operator in determining the amount of time your request will take and scheduling it accordingly.

PERSON REQUESTING DATA: Put your name here.

HOW TO CONTACT YOU: You give either a phone number of directions on how to contact you in case any questions arise concerning your request or to notify you that your request has been fulfilled.

INPUT

WORK FILE ALREADY GENERATED LABELED:

If a previous request has generated a work tape containing the needed data, you can save time by using that tape. you should specify the labeling of that tape or make reference to the request that created it.

Generate Work File

If a previous work file has not been generated, the user must specify the parameters used in generating the work file.

A. DELETE/SELECT PARAMETERS:

If at all possible the user should write and keypunch his own parameter statement. If this is not possible, he should write his request as clearly as possible so that the operator will not have difficulty in writing a statement from it.

B. SORT PARAMETERS:

The user should list the sequence in which he wishes his data to be sorted.

SEQUENCE LIST: This is used by the system operators to code the sequence into machine code.

C. LABEL WORK TAPE AS FOLLOWS:

If this tape is to be used in a later analysis, it must be labeled. The user may specify this labeling.

D. DATE TAPE GENERATED:

This date is entered by the system operator when he creates the work file

BY: operator's name

Output

A separate request should be made for each analysis even though the same data is used in both cases.

Item Analysis

Includes total count for item, subcount for specific groupings within item, subgroup percentage of total count, average latency and standard deviation for each subgroup.

Detail Listings

This is a listing of each response showing date, EPID, match I.D., response, latency, switches, and nonzero counters.

Because of the relatively slow printer speed, this type of listing should be avoided if at all possible as each response may require two or more lines.

Other

If any other type of output is requested, it should be entered in DETAIL in this section and any special programs required attached to the request.

Date Completed:

This should be entered by the system operator when he finishes the run

Save Work Tape for Future Analyses:

If the work tape is to be used for future analysis, check this box.

APPENDIX C

BOOKLET INTRODUCTION TO PHYSICS

APPENDIX C

INTRODUCTION TO PHYSICS
COMPUTER-ASSISTED INSTRUCTION CENTER
FLORIDA STATE UNIVERSITY

1968

INTRODUCTION TO PHYSICS

Welcome to the CAI Center of Florida State University!

CAI stands for Computer-Assisted Instruction which, in a sense, is a method of private tutelage which, hopefully, will give you more depth and understanding in your subject area. The line of communication between you and your tutor, the computer, is through the terminal at which you are sitting. However, to be able to communicate with the computer there are a few basic facts you need to know.

You have two media at your terminal by which to enter answers to be processed by the computer the keyboard, and the light pen.

Your first activity at the terminal will be to "sign on" to your course. This is accomplished by holding down the altn coding key (refer to figure 1) and the index key. Then, type "on p107/s11" (the student number that was assigned to you here in the Center should be substituted for s11).

The first media to be discussed is the light pen. The light pen is located on the lower right side of the screen. When you use the light pen:

1. Be sure of the area you wish to touch with your light pen.
2. Press the area firmly and steadily with the light pen.
3. Withdraw the pen without dragging it across the screen.

NOTE: A "P" will appear in the lower right hand corner of the screen when a light pen response is required. This "P" must appear before you select your answer.

The other response device is the keyboard. The keyboard has 44 keys, allowing 88 characters (44 upper-case and 44 lower-case). In addition, there are 8 function keys, such as c/r, back space, shift, etc., and an alternate coding key. The alternate coding key in combination with the function or with some of the regular keys can provide an additional 38 characters.

NOTE: There are several keys that may seem similar to other keys. For example, the numeral "0" resembles the letter "O" and the numeral "1" (one) resembles the lower case "l" (el). Be careful to use the correct character in your response. Failure to do this may result in the computer analyzing your response incorrectly.

Four of the combinations of the function key and the alternate coding key will be of particular help to you. These combinations will allow you to:

1. Signal the computer that you have typed an answer and it is ready to be processed--this is the "enter" command.

2. Cancel an answer that you have typed.

3. Erase part of all of an answer you have typed.

4. Use subscripts and superscripts in your responses.

Just as with the light pen responses, in keyboard responses a "K" will appear in the lower right corner of the screen.

Now, let's discuss the features of each of the preceding combinations:

Enter command after typing in your answer.

1. Hold down the alternate coding key and, while holding it down, press the space bar.

2. Release both the alternate coding key and the space bar.

The enter command is used only when making a keyboard response.

Cancelling an answer.

If you enter an answer and make a mistake or change your mind, (before using the enter command) you may *cancel* your response by:

1. Pressing the alternate coding key and while pressing it, press the dash key (-).

2. Release the keys and perform the enter command.

You may then enter another response. (Cancelling may be done only *before* you have entered the enter command.)

Erase a letter or total answer.

If you enter one or more incorrect characters and wish to correct them:

1. Press the alternate coding key and while holding it, press the backspace key. Press the backspace key once for each character you want to erase.

2. Release the keys, type the correct character or characters.

3. Perform the enter command.

Superscripts and subscripts.

At times you will need to enter responses with a subscript such as mv_2 and superscripts such as 10^{-2}.

Superscripts.

1. Press the rev index key, but do not hold.

2. Type your superscript.

3. Press the index key. This will return the cursor to the original line of text.

NOTE: The cursor is a lighted "box" that appears on the screen at the position where the next character will appear. It is important that the cursor be returned to the original line of text because it could result in an improperly recorded answer.

Subscripts.

When you are ready to write a subscript:

1. Press the index key.
2. Enter the subscript.
3. Press the rev index key.

Subscripting as you can see is just the opposite of superscripting, and like superscripting, it is important to return the cursor to the original line of text.

Sign off.

To stop at the end of a lesson, you execute the attention command. As in signing on to the course, the attention command is executed by holding down the alternate coding key and while still holding it, press the index key, then release both. The cursor will appear at the lower left of the screen. At this time, type "of" and perform the enter command. This will be erased and the message "you have been signed off" will appear.

Now, for some examples on the terminal using the different commands that have been discussed.

Outline of Lecture 1

Introduction

Nature of Course.

Procedure.

What physics is and what a physicist does.

a) Physics is the study of the motion of matter through time and space.

b) Physicists observe and measure phenomena in order to understand and describe them.

Measurement: Magnitude of an unknown quantity is determined by comparison with a standard magnitude.

MKS system.

Outline of Lecture 2

Measurement & Scientific Notation

rs of ten.

ficients x power of ten.

s for writing large numbers in scientific notation (large numbers being ers greater than 1):

1. Move decimal point just to the right of the first non-zero digit.
2. Magnitude of ten to be used equals number of places from original decimal point to new one.
3. Coefficient may be rounded off if less precision is required.

Figure 1.

$409{,}000{,}000 = 4.09 \times 10^{8}$

$36{,}000 = 3.6 \times 10^{4}$

$5{,}000{,}000 = 5 \times 10^{6}$

Figure 2.

$.000943 = 9.43 \times 10^{-4}$

$0.01003 = 1.003 \times 10^{-2}$

$0.9 = 9 \times 10^{-1}$

es for scientific notation:

1. To add or subtract, the power of ten of both numbers must be the same.

Lecture 2 cont'd.

Figure 3.

$$(4 \times 10^5) + (9 \times 10^5) = 13 \times 10^5 = 1.3 \times 10^6$$

$$(3.1 \times 10^7) - (2 \times 10^6) = (31 \times 10^6) - (2 \times 10^6) = 29 \times 10^6 = 2.9 \times 10^7$$

$$(4 \times 10^{-3}) + (5 \times 10^{-3}) = 9 \times 10^{-3}$$

2. To multiply, first multiply coefficients together, then add the powers of ten.

Figure 4.

$$(4 \times 10^2) \times (2 \times 10^6) = (2 \times 4) \times 10^{(2 + 6)} = 8 \times 10^8$$

$$(9 \times 10^{-3}) \times (3 \times 10^6) = (9 \times 3) \times 10^{(-3 + 6)} = 2.7 \times 10^4$$

3. To divide, first divide the coefficients, then subtract the power of ten of the divisor from the power of ten of the dividend.

Figure 5.

$$\frac{1.5 \times 10^{14}}{3 \times 10^8} = \frac{1.5}{3} \times 10^{(14 - 8)} = .5 \times 10^6 = 5 \times 10^5$$

$$\frac{6 \times 10^5}{3 \times 10^{-2}} = \frac{6}{3} \times 10^{(5 - (-2))} = 2 \times 10^{5 + 2} = 2 \times 10^7$$

$$\frac{300 \times 10^{-8}}{6 \times 10^{-2}} = \frac{300}{6} \times 10^{(-8 - (-2))} = 50 \times 10^{(-8 + 2)} = 50 \times 10^{-6} = 5.0 \times 10^{-5}$$

Lecture 2 cont.

Order of magnitude.

Figure 6.

Order of magnitude of 1.5×10^8 is 10^8

Order of magnitude of 3.6×10^8 is 10^8

Order of magnitude of 4.9×10^8 is 10^8

Order of magnitude of 5.5×10^8 is 10^9

Figure 7.

1.3×10^7 "rounds off" to 1×10^7 which has order of magnitude 10^7

9.0×10^7 "rounds off" to 10×10^7 which has order of magnitude 10^8

5.0×10^3 "rounds off" to 10×10^3 which has order of magnitude 10^4

and notice the following two:

9.01×10^{-13} "rounds off" to 10×10^{-13} which has order of magnitude 10^{-12}

1.01×10^{-13} "rounds off" to 1×10^{-13} which has order of magnitude 10^{-13}

Lecture 2

Exponents

In order to understand even very elementary physics, you need to know something about exponents, roots, and the power laws. This is the subject which we will take up now.

Positive Integral Exponents

Consider the relationship $3 \times 3 = 9$. We say that the number 3 has been squared, or raised to the second power. This expression can also be expressed in symbols as $3^2 = 9$. The superscript number 2 is called an exponent; the number 3 is called the base. We also say that 3 is the square root of 9.

By extension: $3 \times 3 \times 3 = 27 = 3^3$. We say that 3 has been cubed, or raised to the third power. We say that 3 is the cube root of 27, and the exponent is also 3, in this particular case.

For the general case: $x \cdot x \cdot x \cdot \cdots$ n times $= x^n$ (i.e., x used as a factor n times) n is called the exponent; we say we have raised x to the n^{th} power; and we say that x is the n^{th} root of x^n.

Negative Integral Exponents

Negative exponents are also used frequently in physics.

We define X^{-n} as $\frac{1}{X^n}$.

We say that X has been raised to the negative n power and we call (-n) the exponent.

Some examples:

$$2^{-2} = \frac{1}{2^2} = \frac{1}{4}$$

$$3^{-2} = \frac{1}{3^2} = \frac{1}{9}$$

$$2^{-5} = \frac{1}{2^5} = \frac{1}{32}$$

Fractional Exponents

Fractional exponents are also defined in physics and math. We define $X^{\frac{1}{n}}$ as the n^{th} root of X and $X^{\frac{m}{n}}$ as the n^{th} root of X^m. We say that X has been raised to the $\frac{1}{n}$ or the $\frac{m}{n}$ power, respectively. For example: $X^{\frac{1}{3}}$ = the cube root of $X^1 = \sqrt[3]{X}$ and $X^{\frac{3}{2}}$ = the square root of $X^3 = \sqrt{(X^3)}$.

We will not deal with fractional exponents in this course; however, it might ell to remember that $X^{\frac{1}{2}}$ means the square root of X.

The rules for negative fractional exponents are the same as for negative egral exponents. In other words:

$$X^{\frac{-1}{n}} = \frac{1}{X^{1/n}}$$

$$X^{-m/n} = \frac{1}{X^{m/n}}$$

Now we want to know how to work with numbers which are expressed in exponential n. Such rules are known as power laws.

ition and Subtraction

There are no easy rules for the addition and subtraction of numbers which been raised to a power. In order to work with them, it is necessary to orm the exponentiation and then to add or subtract.

For example:

$2^5 + 3^2 = 32 + 9 = 41$ Perform exponentiation first.

$3^3 - 2^3 = 27 - 8 = 19$

$5^3 + 5^2 = 125 + 25 = 150$ Perform exponentiation first.

iplication and Division

Different Base - Same Exponent

This is a highly restricted situation, with which we will not be concerned his course. However, it is interesting to know that $(A^n)\ (B^n) = (AB)^n$. example:

$(4^2)\ (2^2) = (16)\ (4) = (64) = (\ (4)\ (2)\ )^2 = 8^2 = 64$

Also: $\dfrac{A^n}{B^n} = \left(\dfrac{A}{B}\right)^n$

For example: $\dfrac{10^2}{5^2} = \dfrac{100}{25} = 4 = \left(\dfrac{10}{5}\right)^2 = 2^2 = 4$

and $\dfrac{4^3}{2^3} = \dfrac{64}{8} = 8 = \left(\dfrac{4}{2}\right)^3 = 2^3 = 8$

The exact same rules hold for negative exponents. For example:

$$\frac{4^{-2}}{2^{-2}} = \frac{\frac{1}{4^2}}{\frac{1}{2^2}} = \frac{1}{16}\left(\frac{4}{1}\right) = \frac{1}{4} = 2^{-2} = \left(\frac{4}{2}\right)^{-2} = (2)^{-2} = \frac{1}{2^2} = \frac{1}{4}$$

But we can say nothing about the multiplication or division of numbers having different bases and different exponents. For example:

$$2^3\ 3^2 = (8)\ (9) = 72$$

and

$$\frac{10^3}{3^2} = \frac{1000}{9} = 111.1$$, a repeating decimal.

II. Same Base - Different Exponents

This is the case which will be of particular use to us in this course: the case in which we multiply or divide numbers having the same base, but different exponents. In the powers-of-ten notation with which we will be working, the base is, of course, always 10, but the following rules hold for any base.

Rule 1, multiplication: $(A^n)\ (A^m) = A^{n+m}$

For example: $(2^2)\ (2^3) = (4)\ \ (8) = 32$, but $32 = 2^5 = (2)^{2+3}$

For negative exponents, exactly the same rules apply. $(A^n)\ \ A^{-m})$ would be

$A^{n+(-m)} = A^{n-m}$. While $(A^{-n})\ \ (A^{-m}) = A^{-n-m} = A^{-(n+m)}$

For example: $(2^3)\ (2^{-1}) = (8)\ (\tfrac{1}{2}) = 4$, but $4 = 2^2 = 2^{(3-1)}$

Rule II. Division $A^n/A^m = A^{n-m}$

This rule holds equally for positive and negative exponents.

Some examples:

$$\frac{2^5}{2^2} = \frac{32}{4} = 8 \qquad \text{But } 8 = 2^3 = 2^{(5-2)}$$

$$\frac{2^5}{2^{-2}} = \frac{32}{\frac{1}{2}^2} = \frac{32}{\frac{1}{4}} = 128 \qquad \text{But } 128 = 2^7 = 2^{5-(-2)}$$

$$\frac{2^{-2}}{2^{-1}} = \frac{\frac{1}{2^2}}{\frac{1}{2}} = \left(\frac{1}{4}\right)\left(\frac{2}{1}\right) = \frac{1}{2} \qquad \text{But } \frac{1}{2} = 2^{-1} = 2^{(-2-(-1))}$$

There is one more rule which will be useful to know: $(A^n)^m = A^{nm}$

Example: $(2^2)^3 = (4)^3 = 64$ But $64 = 2^6 = 2^{(2)\ (3)}$

This concludes our summary of the power laws. It is important also that you gain an appreciation of the equivalence of such pairs as those shown on the following pages.

$$1580 \times 10^{20} = 1.580 \times 10^{23}$$

$$.1520 \times 10^{20} - 1.520 \times 10^{19}$$

These numbers are both expressed in terms of positive powers of 10. Study them carefully until you understand fully why the equalities hold. Notice that every time you move the decimal point one place to the left, you must increase the power of 10 by 1, in order to keep the total value of the number unchanged. And each time you move the decimal one place to the right you must decrease the power of 10 by 1. Can you see why this happens?

Now, look at a pair of very small numbers (negative exponents).

$$1580 \times 10^{-20} = 1.580 \times 10^{-17}$$

$$.1580 \times 10^{-20} = 1.580 \times 10^{-21}$$

Let's look carefully at the first case:

$$1580 \times 10^{-20} = 1.580 \times 10^{-17}$$

We moved the decimal point three places to the left, so we must make the other part of the number larger by increasing the exponent by 3. It was originally -20, so adding +3 gives us -17. So the number is written 1.580×10^{-17}. Although 17 is smaller than 20, we are increasing the exponent because -17 is less negative than -20.

Outline to Lecture 3 on Scaling

The symbol $\propto$ means "is proportional to"

Functions:

Linear	$A \propto B$
Inverse	$A \propto 1/B$
Quadratic	$A \propto B^2$
Inverse Quadratic	$A \propto 1/B^2$

Scale factor: the factor X that the dimensions of a physical object have been multiplied by in order to retain its shape while changing its size.

Certain geometric properties have simple functional dependences on the scale factor X.

length	$l \propto X$
area(surface or cross-sectional)	$A \propto X^2$
volume	$V \propto X^3$

Certain physical properties are functions of certain geometric properties, and therefore, also depend on the scale factor X.

strength $\propto$ cross-sectional area, therefore $\propto X^2$

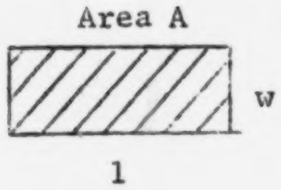
heat production $\propto$ volume, therefore $\propto X^3$

heat loss $\propto$ surface area, therefore $\propto X^2$

Area.

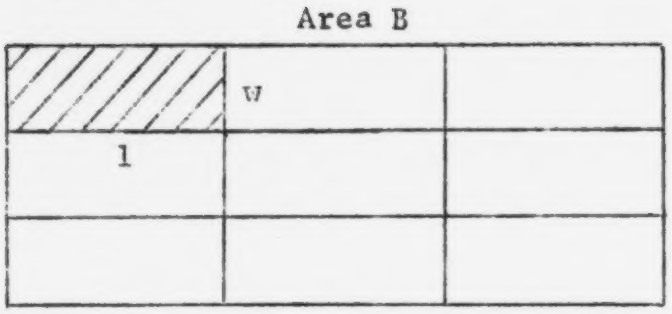
Figure I

a.



length = 1
width = w
Area A = (1) (w)

b.



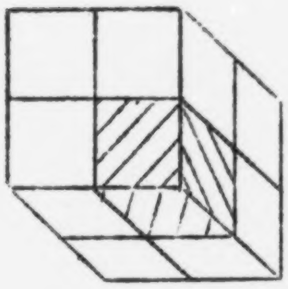
$A \propto 3^2$

scale factor=3
length = (3) (1)
width = (3) (w)
area B=(3) (1) (3) (w) = 9 lw
area B = 9(Area A)
$= 3^2$ (Area A)

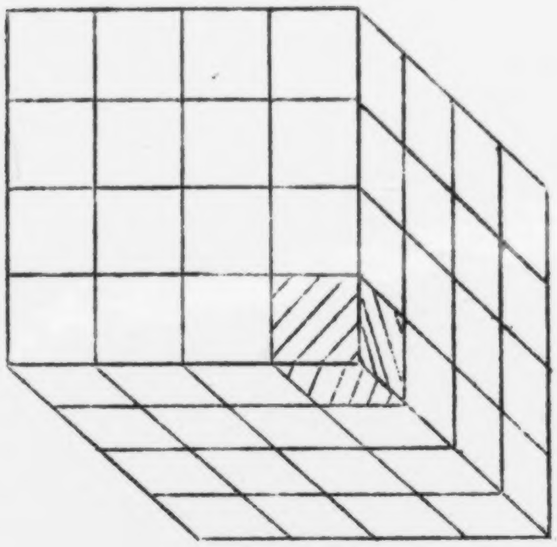
Volume.

Figure II

a.



b.



$V \propto 2^3$

l = 2 w = 2 h = 2
volume A = lwh
= (2)(2)(2)
= 8

scale factor 2
l = (2)·(2)=4 w= (2)·(2)=4
h = (2)·(2)=4

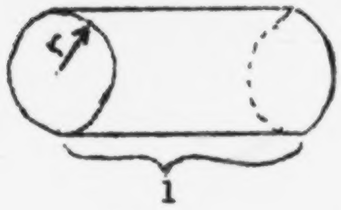
volume B = lwh
= (4)(4)(4) = 64
= 8 (volume B)
$= 2^3$ (volume B)

Cross-sectional Area.

Figure III

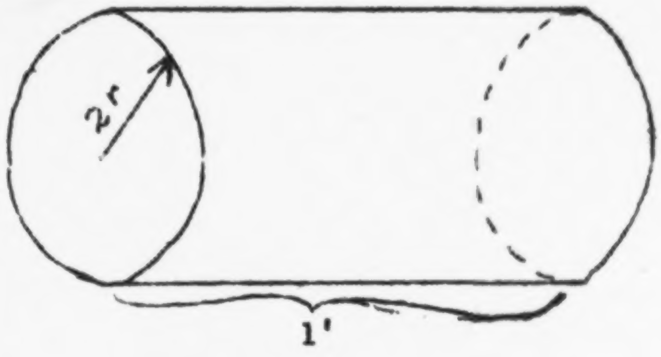
Let's take the cross-sectional area of a cylinder since this is a simple example:

a.



Area A = $(\pi)(r^2)$

b.



scale factor = 2
Area B = $\pi(2^2)\ r^2 = 4\pi r^2$
Area B = 4(Area A) = 2^2 (Area A)

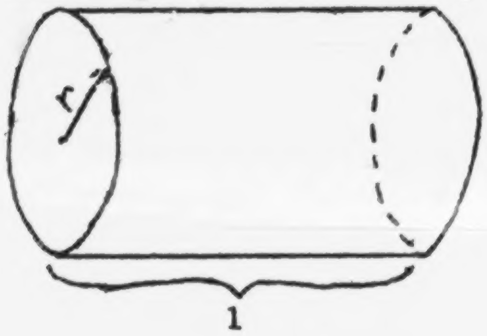
You can see from this example that the area is proportional to the square of the scale factor. The length does not enter into this calculation at all.

Surface area.

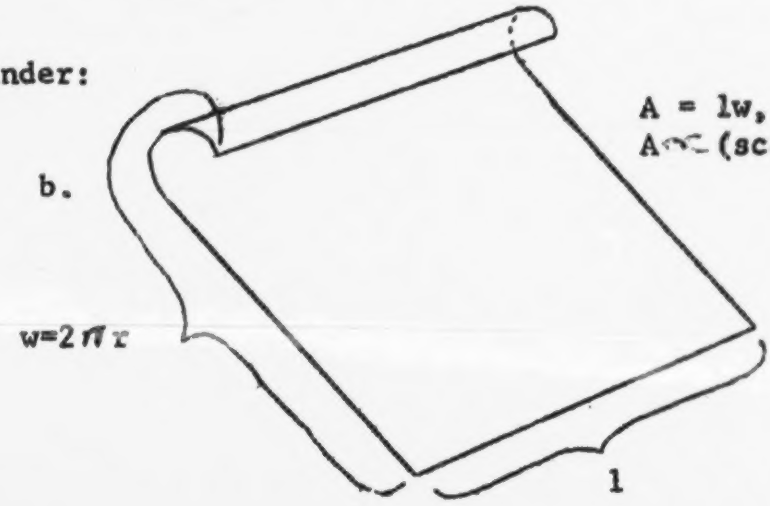
Figure IV

Surface area is a little harder to see at first, but let's again look at the cylinder:

a.



b.



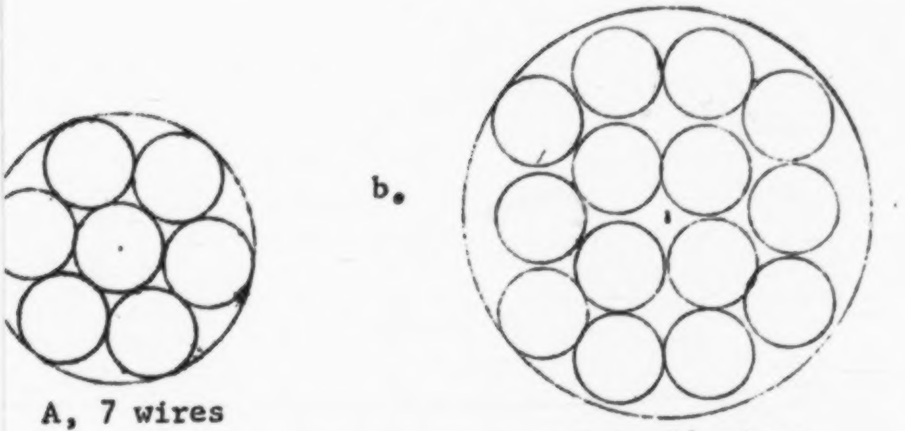
A = lw,
A $\propto$ (scale factor)^2

If we imagine unrolling the cylinder, we can see that we have simply a flat sheet the length of which is the length of the cylinder, and having a width equal to $2\pi r$, where r is the radius of the cylinder when it is rolled up. Since surface area is equal to lw, we can see that if each of these dimensions is scaled up by X, surface area $\propto X^2$.

Strength.

We have previously shown that cross-sectional area is proportional to X^2 where X is the scaling factor. It is simple to show that strength is proportional to the cross-sectional area. Imagine a cable made up of a number of steel wires bundled together:

Figure V



A, 7 wires

2 A, 14 wires

$A \propto X^2$

strength $\propto A$

strength $\propto X^2$

If we double the cross-sectional area, we can now fit twice as many wires of the same size into the cable. This makes sense; it would be rather hard to break a straw broom in half, although the individual straws break easily enough.

Since, as we have already seen, cross-sectional area is proportional to the scaling factor X-squared, strength must also be proportional to X^2,

OUTLINE OF LECTURE 4

Figure 1a.

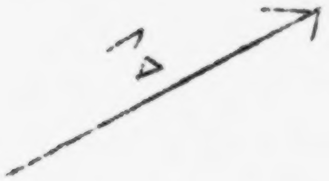


Figure 1b.

Figure 1c.

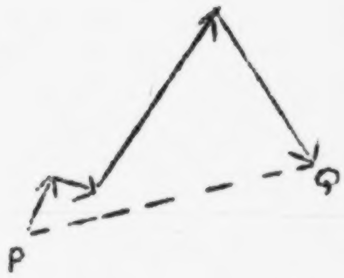
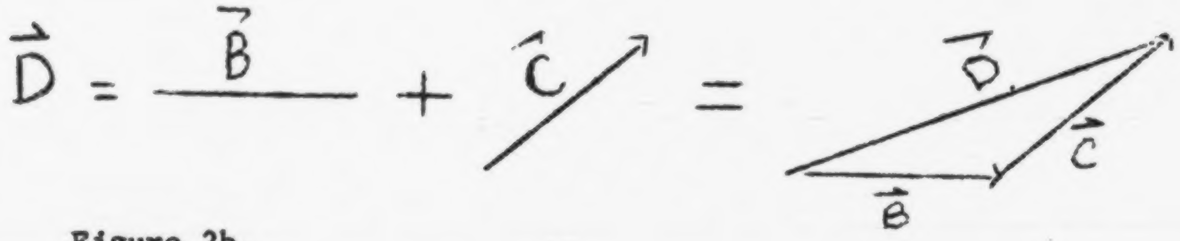
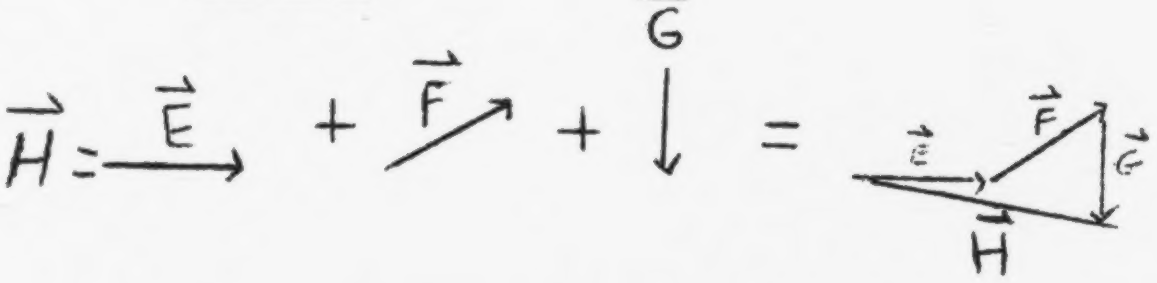


Figure 2a.



$\vec{D}$ =
$\vec{B}$
+
$\vec{C}$
=
$\vec{D}$
$\vec{C}$
$\vec{B}$

Figure 2b.



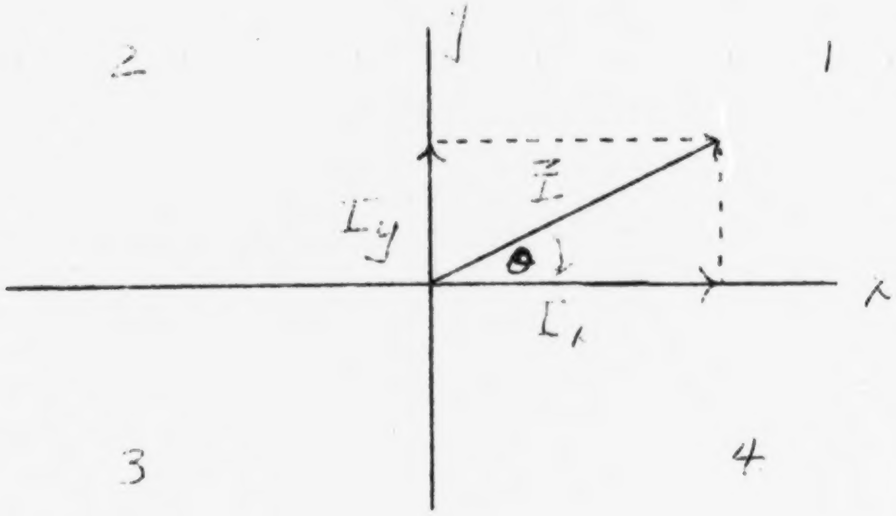
$\vec{H}$ =
$\vec{E}$
+
$\vec{F}$
+
$\vec{G}$
=
$\vec{E}$
$\vec{F}$
$\vec{G}$
$\vec{H}$

Scalars add like numbers.

Vectors have both magnitude and direction, so their addition is more complicated than numbers.

One way of adding vectors is by scale drawings, placing the tail of one vector at the head of another, but keeping the direction of each vector unchanged. The sum is equal to the vector constructed from the tail of the first vector to the head of the last.

Figure 3.

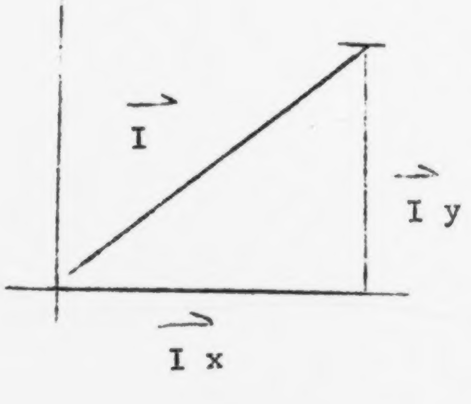


x component of $\vec{I}$ = magnitude of $\vec{I}$ times cos θ = I_x

y component of $\vec{I}$ = magnitude of $\vec{I}$ times sin θ = I_y

To resolve a two dimensional vector into its cartesian components just project it into the x and y axes. If you add these components, you get the original vector back.

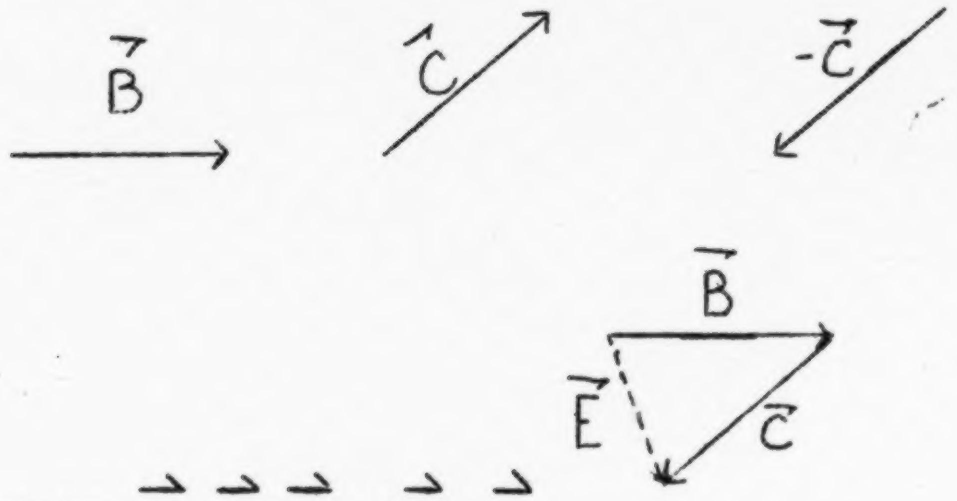
Figure 3b



vector equation $\vec{I} = \vec{I_x} + \vec{I_y}$

equation of magnitudes: $I^2 = I_x^2 + I_y^2$

Figure 4.


$\vec{B}$
$\vec{C}$
$-\vec{C}$
$\vec{B}$
$\vec{E}$
$\vec{C}$

Subtraction: $\vec{B} - \vec{C} = \vec{B} + (-\vec{C}) = \vec{E}$

Figure 5.

$$\vec{A} - \vec{A} = \vec{A} + (-\vec{A}) = 0$$

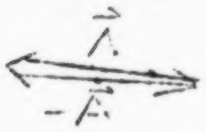
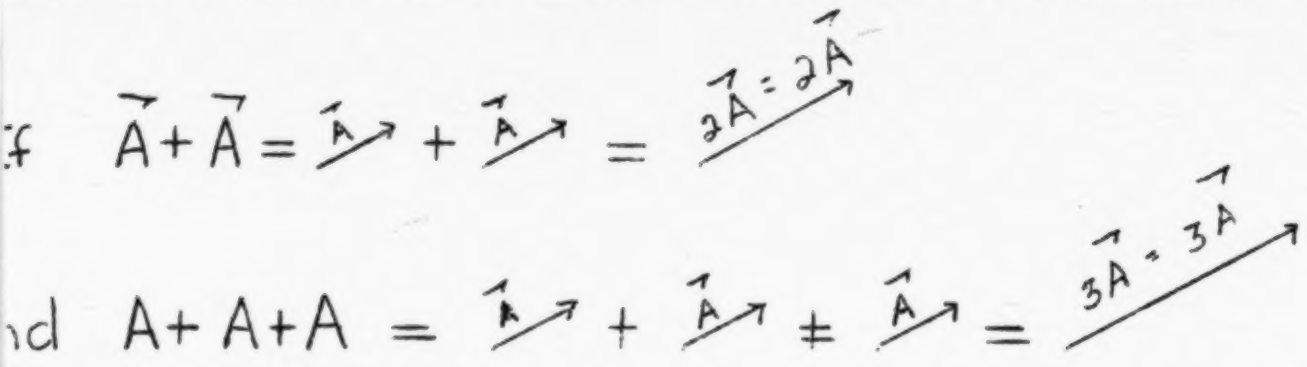


Figure 6.

ultiplication of vectors is simply a short way to add, as in ordinary arithmetic.



f $\vec{A}+\vec{A}=$ $\vec{A}$ + $\vec{A}$ =
$2\vec{A} = 2\vec{A}$
d A+ A+A = $\vec{A}$ + $\vec{A}$ ± $\vec{A}$ =
$3\vec{A} = 3\vec{A}$

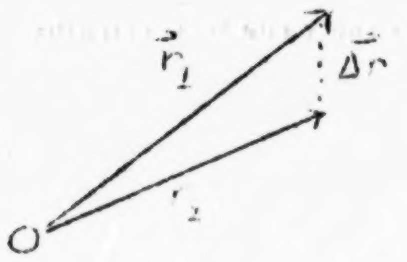
Similarly, $3(-\vec{A}) = -3\vec{A}$

then $q\vec{A}$, where q is a scalar quantity, must mean

$\vec{A} + \vec{A} + \vec{A} + \ . \ . \ .$ q times.

$q\vec{A}$ represents a vector q times as long as $\vec{A}$, and in the same direction as $\vec{A}$ if q is positive and in the opposite direction if q is negative.

Figure 7


$\vec{r}_1$
$\Delta\vec{r}$
r_2
O

$\vec{r}_1$: Displacement at time t_1

$\vec{r}_2$: displacement at time t_2

$\Delta\vec{r}=\vec{r}_2-\vec{r}_1$ or: $\vec{r}_2=\vec{r}_1+\Delta\vec{r}$

$\Delta t=t_2-t_1$

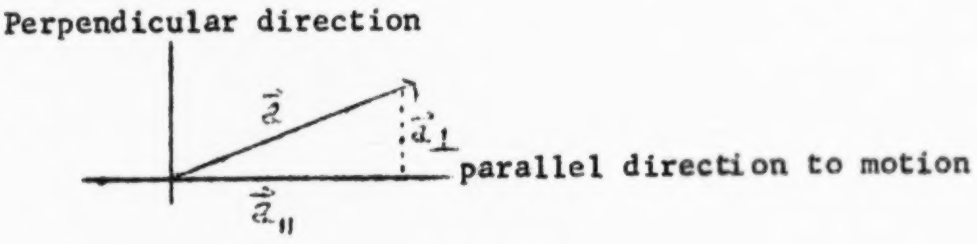
average velocity in interval Δt: $\vec{v}=\Delta\vec{r}/\Delta t$ or: $\Delta\vec{r}=\vec{v}\Delta t$

$\vec{r}_2=\vec{r}_1+\Delta\vec{r}=\vec{r}_1+\vec{v}\Delta t$

instanteneous velocity $\vec{v}_i=\underset{\Delta t \to 0}{\text{limit}}\ \Delta r/\Delta t$

If $\vec{v}_i$ =average $\vec{v}$ for every instant of the motion, the result is straight line, uniform motion.

acceleration $\vec{a}=\Delta\vec{v}/\Delta t$ or: $\Delta\vec{v}=\vec{a}\Delta t$


Perpendicular direction
$\vec{a}$
$\vec{a}_\perp$
parallel direction to motion
$\vec{a}_\parallel$

$\vec{a}=\vec{a}_\parallel+\vec{a}_\perp$

Two special cases of constant acceleration:

1. $\vec{a}_\perp=0$. $\vec{a}_\parallel$ changes the magnitude of $\vec{v}$, but not the direction

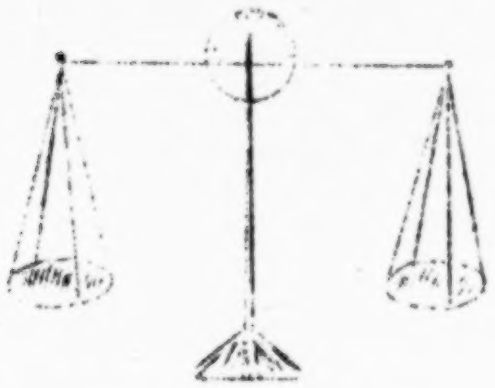
2. $\vec{a}_\parallel=0$. $a_\perp$ changes only the direction of $\vec{v}$, not the magnitude. If $\vec{a}$ has only this component, the result is uniform circular motion - constant speed but not constant velocity.

Outline of Lecture 5

Mass: An operational definition is used. The mass of an object is defined by comparison to a standard measure of mass, using a beam balance.

Thus defined, mass does not change from one location to another (as does weight); nor does it change with temperature (as does volume).

Figure 1--a Beam Balance



Solid: matter which has a definite crystalline structure

Model Construction:

I. Make observations.

II. Invent a model tying together the observations.

III. Make predictions from the model and test them experimentally.

Model for a gas:

1. A gas consists of widely spaced particles called molecules, in a continuous state of random motion.
2. These molecules are very weakly bound together.
3. The pressure on the walls of the container is defined to be the average push over the surface of the wall due to collisions of the molecules with the wall.
4. The average speed of the molecules is a function of temperature such that the higher the temperature, the higher the average speed.

From this model, it follows that:

For a constant amount (number of molecules) of a gas in an airtight container: (let P = pressure, V = volume, T= temperature)

$P \propto 1/V$ for constant temperature

$P \propto T$ for constant volume

These two relationships have been shown experimentally to be correct.

They can be combined into the following law for an ideal gas:

$PV \propto T$

FILM NOTES

#80-296 PROPERTIES OF GAS

OBJECTIVE

To demonstrate some properties of a gas.

BASIC THEORY

The behavior of a gas can be determined by considering the individual particles of which it is composed.

DEMONSTRATION APPARATUS

Cylindrical disks, which look like hockey pucks, are set in motion on a horizontal table. The pucks are effectively floated by means of jets of air directed upwards through a multitude of holes, thus providing movement which is nearly frictionless. The walls of the table are agitated at a set frequency to maintain the pucks at the same average speed.

DEMONSTRATION PROCEDURE

Pressure. Due to the collision of gas particles on a wall, the wall exerts a force on the particles since their directions are changed, and therefore, the particles exert an equal and opposite force on the wall. The average force, divided by the area is the pressure. We can take the number of collisions in a time interval as a measure of the pressure.

1 For a first observation, the walls are vibrated at 2.8 vib/sec. Using 24 pucks, the number of collisions in 15 sec against the end wall is ______.

2 Maintaining the 2.8 vibration rate, but increasing the number of pucks to 36, the number of collisions is __________.

What can you say about the effect of the number of particles in a gas on its pressure?

3 Still at 2.8 vib/sec and 36 pucks, but with half the area, the number of collisions is ___________.

What can you say about the effect of volume on the pressure for a fixed number of particles?

4 For 36 pucks and the full area, the vibration rate is increased to 3.6 vib/sec. The number of collisions is __________.

For a fixed number of particles in a given volume, what effect does increasing the speed of the particles have on the pressure? (Compare with part 2)

Isothermal Compression and Expansion.

5 Here we see that during this type of compression process, the speed of the particles, and therefore, the temperature of the gas, doesn't change.

Since we know that the pressure increases (more collisions), we can reach a tentative conclusion that the pressure of a gas varies inversely with its volume, i.e. $P \sim 1/V$.

* It is also to be noted that since the temperature doesn't change, the work done during an isothermal compression must be removed by the external system according to the energy conservation principle - during the expansion, work is done by the gas with the external system supplying the necessary energy as heat.

Adiabatic Compression and Expansion.

6 During this type of compression, work done on the gas leads to an increase in the temperature of the gas.

By definition on adiabatic process, there are transformations between work and energy of the gas - with no exchange of heat with the surroundings.

* Therefore, since no heat is exchanged with the surroundings, in the compression process, work done on the gas goes to increasing the internal energy of the gas - during the expansion, work done by the gas is at the expense of the internal energy.

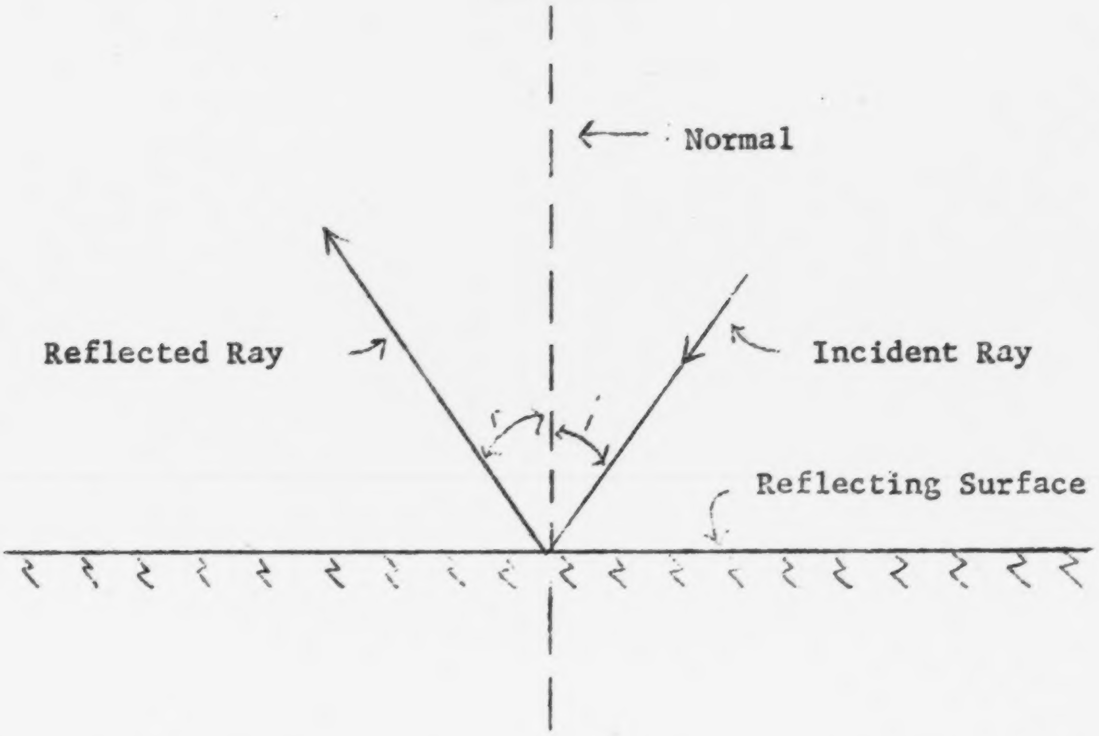
* Optional discussion

Outline of Lecture 6 - Light

The incident ray, the normal, and the reflected ray all lie in the same plane.

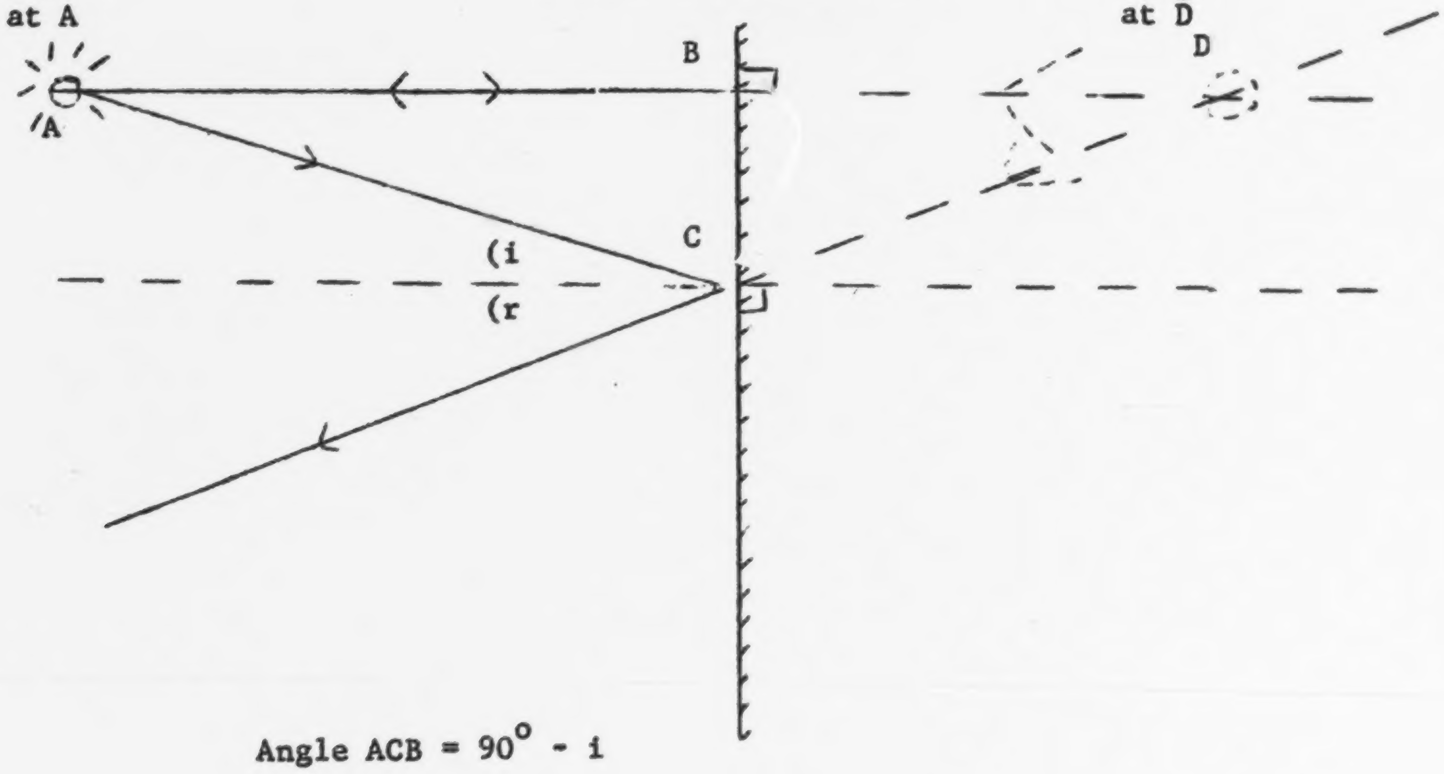
The angle of incidence, i, is equal to the angle of reflection, r.

Figure 1.


Normal
Reflected Ray
Incident Ray
r
i
Reflecting Surface

We can use these laws to find the apparent locations of images formed by mirrors, since we can project the rays which come off the mirror back to their apparent origin.

FIGURE 2 - PLANE MIRROR



Angle ACB = 90° - i

Angle DCB = 90° - i

1. So angle ACB = angle DCB

2. angle ABC = angle DBC (both are right angles

3. BC is common to both triangle BCA and triangle BCD, so triangle

   BCA = triangle BCD

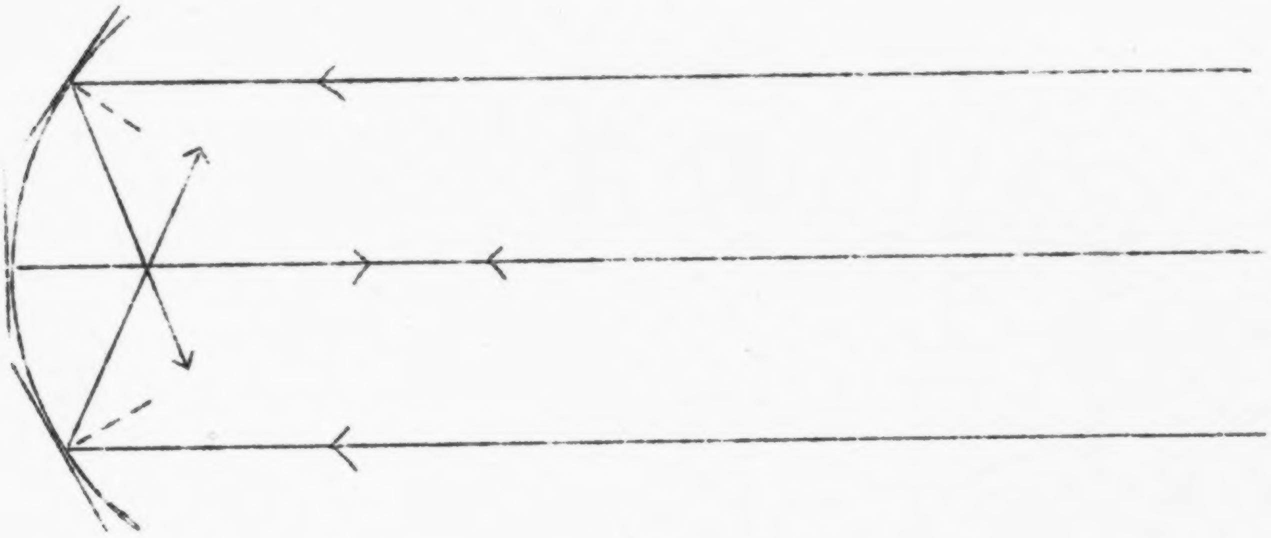
   since 2 angles and 1 side are the same for both.

   Therefore, AB = BD, which means that the image at D is as far behind the mirror as the object at A is in front of it.

   The image formed by a plane mirror is

   1) virtual (the rays do not actually cross the mirror, only appear to)
   2) perverted (right - to - left reversed)
   3) erect (right side up)
   4) as far behind the mirror as the object is in front of the mirror

Figure 3.
A real image is formed by certain curved mirrors.



Real image: an image located by actual light rays instead of extensions of actual light rays.

Figure 4 - Refraction, air to water

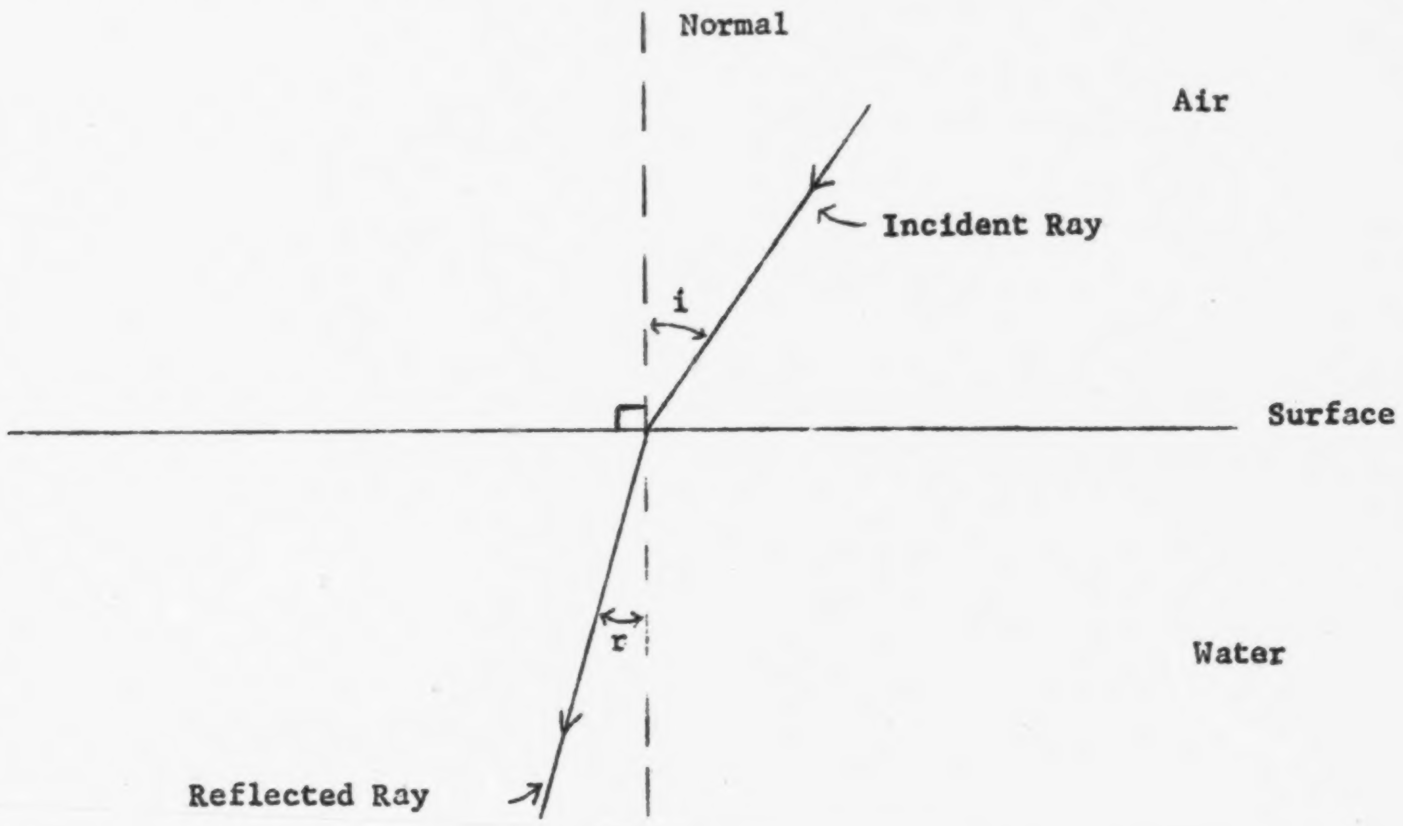
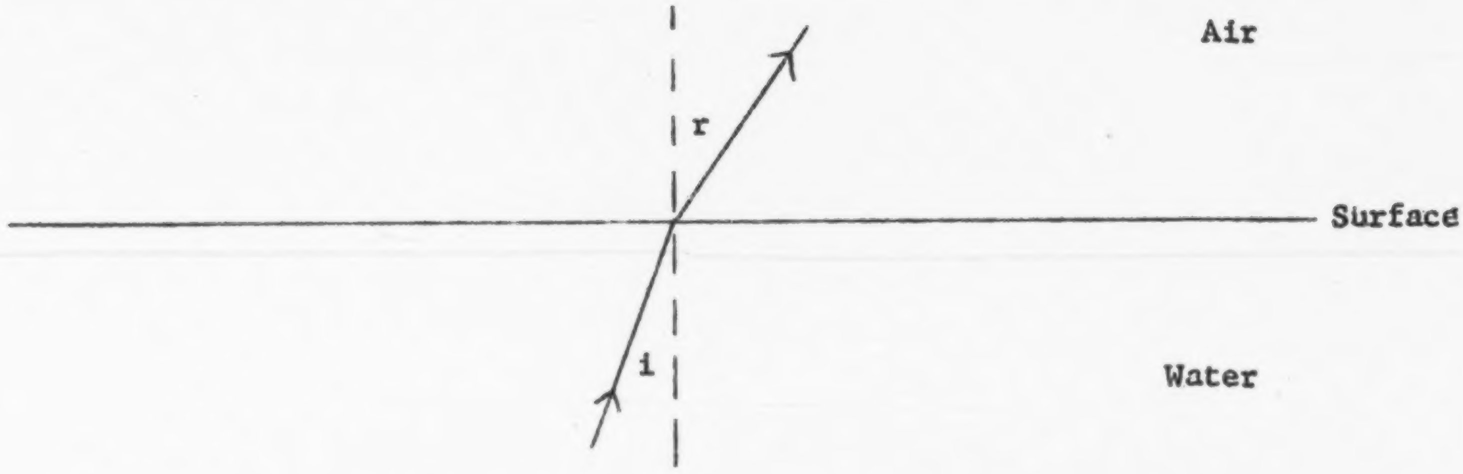

Normal
Air
Incident Ray
i
Surface
r
Water
Reflected Ray

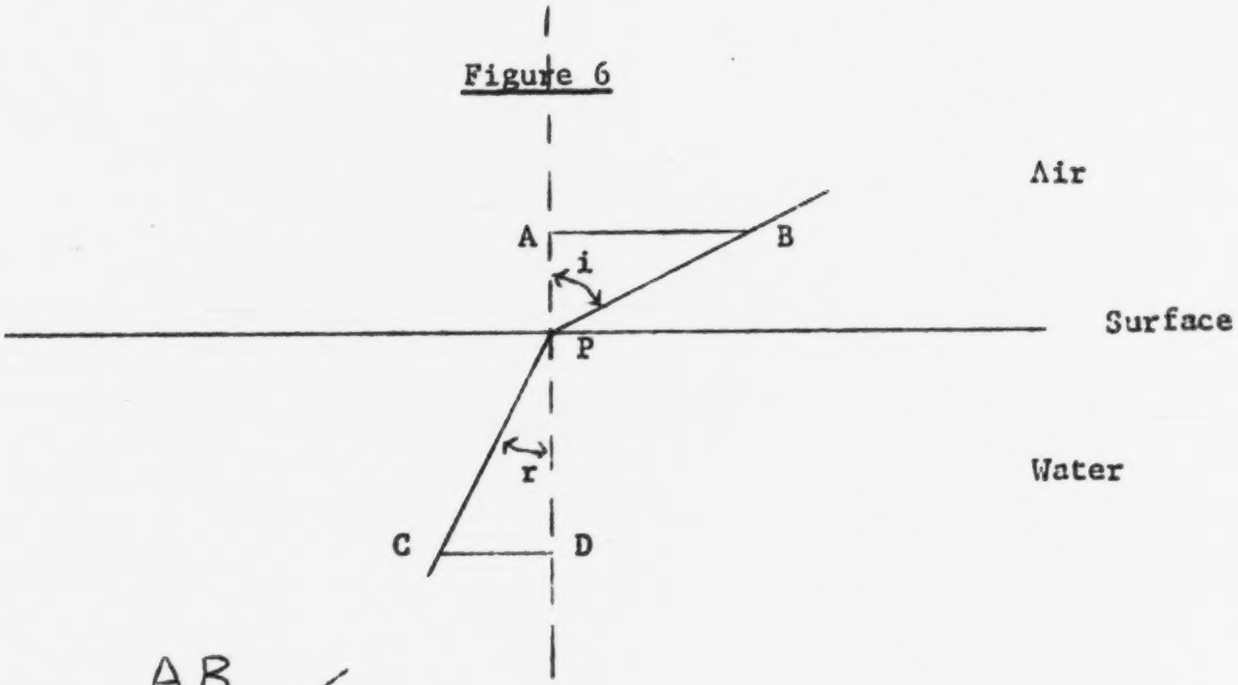
Figure 5 - Refraction, water to air


Air
r
Surface
i
Water

Refraction: bending of the path of light when it travels from one medium to another.

The angle of refraction, r, is measured between the normal to the interface and the refracted ray.

Figure 6


Air
A
B
i
Surface
P
r
Water
C
D

$$\frac{AB}{PB} \Big/ \frac{CD}{PC} = n, \text{ a constant}$$

$$\frac{AB}{PB} = \sin i$$

$$\frac{CD}{PC} = \sin r$$

so $\dfrac{\sin i}{\sin r} = n$ (Snell's Law)

#24 REFRACTION AND REFLECTION OF LIGHT

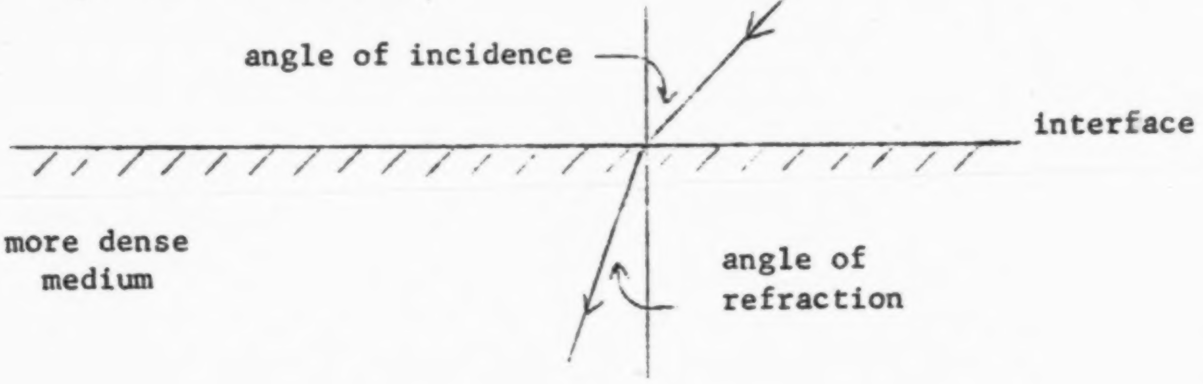
OBJECTIVE

To illustrate the refraction and the reflection of light.

DEMONSTRATION PROCEDURE

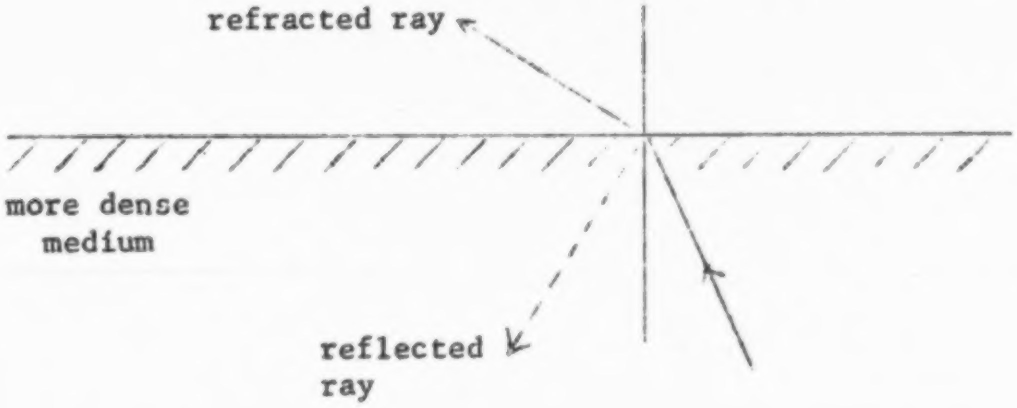
1 Observations are to be made on the angles of refraction (light enters from above) as the angle of incidence is continuously varied from approximately zero to forty-five degrees.

It is observed that there is a definite bending of the ray at the interface between the two media and the angle of refraction is less than the angle of incidence.


angle of incidence
interface
more dense medium
angle of refraction

2 Observations are made on the angle of refraction (light proceeds from below from a more dense medium into air) as the angle of incidence is continuously varied from zero to forty-five degrees.

At about forty-five degrees, the refracted ray reaches ninety degrees and is quite colored. As the incident angle is increased, there is no refracted ray--only a reflected ray - and we have total internal reflection.


refracted ray
more dense medium
reflected ray

Outline of Lecture 7

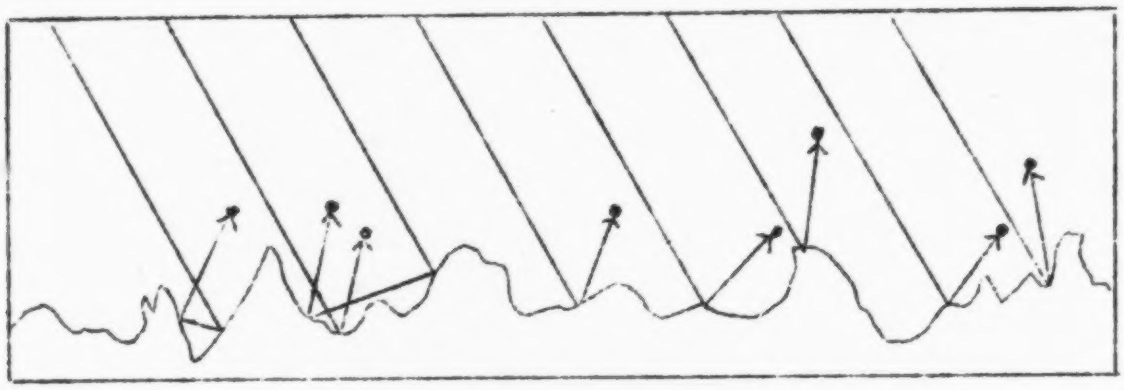


Figure 1 - Diffuse Reflection

PARTICLE MODEL OF LIGHT

Light travels in straight lines.

If light is a collection of particles, they must be extremely small since no interaction between crossing beams of light is ever observed; and extremely fast, since they travel in straight lines.

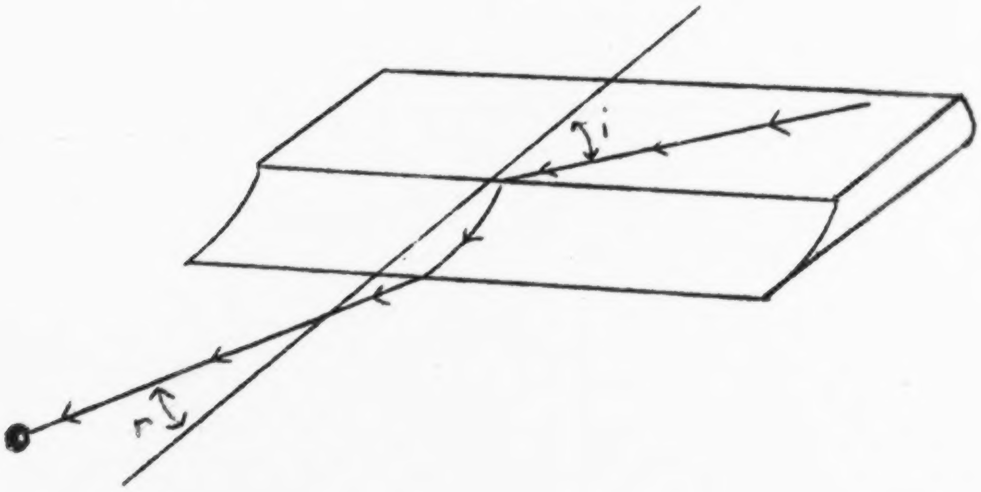
Reflection can be explained by the particle model; light particles reflect like hard smooth balls bouncing off a hard smooth surface.

The particle model can explain refraction. It can be used to derive Snell's law:

$$\frac{\sin i}{\sin r} = \text{constant.}$$

Figure 2

Particle Model: Refraction



If light is like particles, one would expect it to go faster in a denser medium, since we observe that it bends closer to the normal to the interface when it enters a denser medium. Notice that the marble in Figure 2 bends closer to the normal when it is going faster. An explanation for this follows Figure 3.

This is demonstrated in film loop FSU - #23, "Refraction and Reflection: Particle Model."

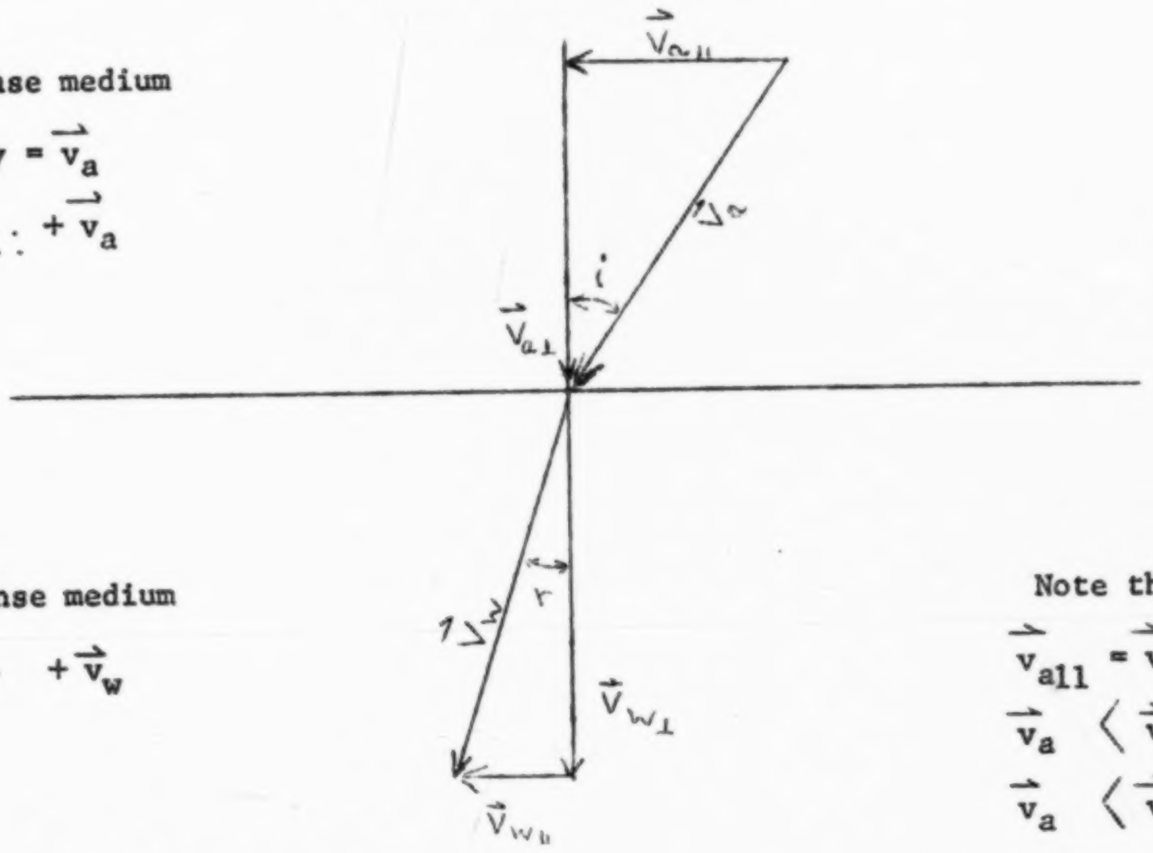
Figure 3.

Particle Model: Snell's Law

s dense medium

ocity = $\vec{v}_a$

= $\vec{v}_{a}$ + $\vec{v}_a$



e dense medium

= $\vec{v}_{w}$ + $\vec{v}_w$

Note that:

$\vec{v}_{a\parallel} = \vec{v}_{w}$

$\vec{v}_a < \vec{v}_w$

$\vec{v}_a < \vec{v}_w$

$<$ means "less than"

The marble speeds up when it rolls down the hill. There is no son for it to gain speed in the direction parallel to the surface, ugh. The increase is wholly in the downward direction while on the l, or in the b direction in Figure 3.

$$\sin i = \frac{v_a}{v_a} \qquad \sin r = \frac{v_w}{v_w}$$

$$\frac{\sin i}{\sin r} = \frac{v_a / v_a}{v_w / v_w}$$

$v_{a\parallel} = v_w$, since the acceleration of gravity does not affect this ponent.

$\frac{\sin i}{\sin r} = \frac{v_w}{v_a} = n$ This is Snell's law.

s the particle model can explain refraction. know, from air-to-water measurements on light, that $\sin i/\sin a > 1$ the particle model predicts that $v_w/v_a > 1$, which means the speed of light faster in water than in air. However, experiments show the opposite.

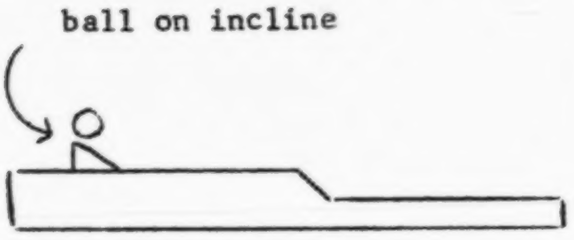
FILM NOTES

#23 REFRACTION AND REFLECTION: PARTICLE MODEL

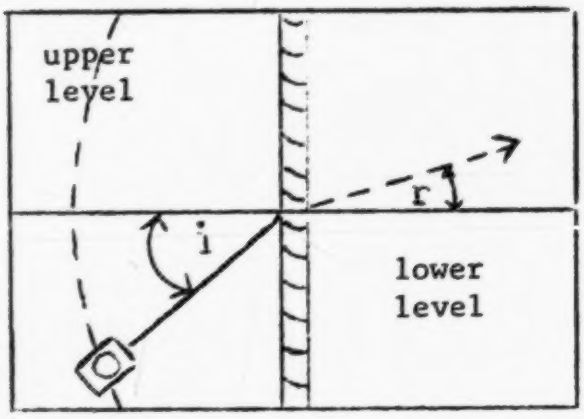
OBJECTIVE

To illustrate reflection and refraction using the particle of light.

DEMONSTRATION APPARATUS



side view



overhead view

DEMONSTRATION PROCEDURE

1 Starting on the upper level, the particles are projected at different angles of incidence i and the angles of refraction r are observed.

With the higher level surface representing a less dense medium, there is qualitative agreement with Snell's Law. A ray is bent towards the normal upon entering a more dense medium.

2 If the particle is projected from the lower level (more dense medium), it is reflected for large angles of incidence.

As the angle of incidence is decreased, the particle is able to penetrate the interface and is refracted, such that the particle path is bent away from the normal.

Outline of Lecture 8

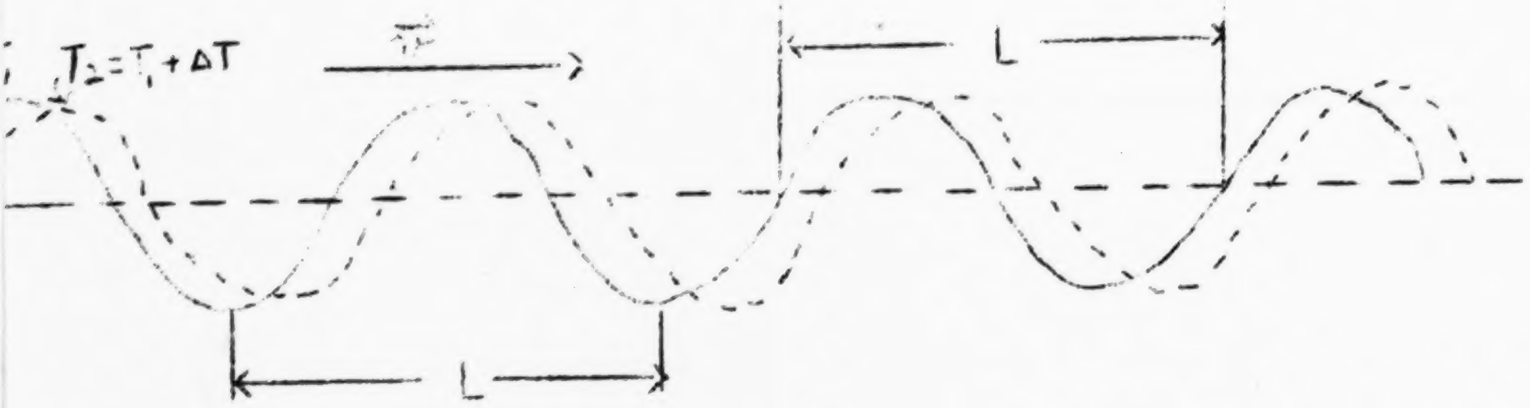


Figure 1.

This wave is going from left to right with speed v.

The distance from trough to trough (or peak to peak) is a wavelength, indicated by L.

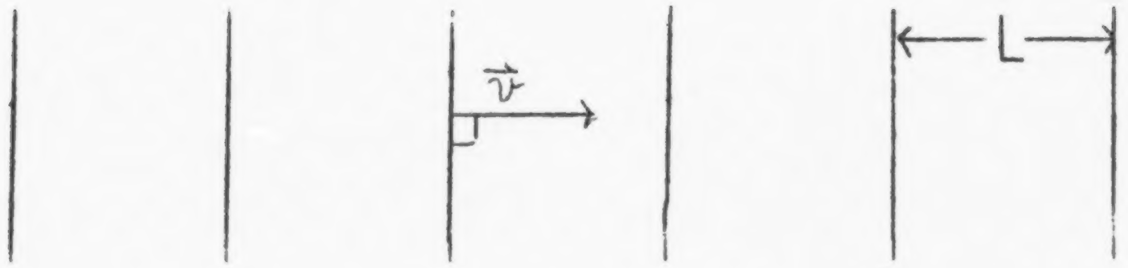
The dotted line represents the same wave at a time Δ t sec later.

T is the period, the time for one wave to pass a stationery point.

T is in sec/wave which is the same as sec/cycle.

v = dist/time = L/T = fL

Figure 2.



The velocity vector $\vec{v}$ is perpendicular to these straight pulses. "Rays" are in the same direction as the velocity vector.

Figure 3a.

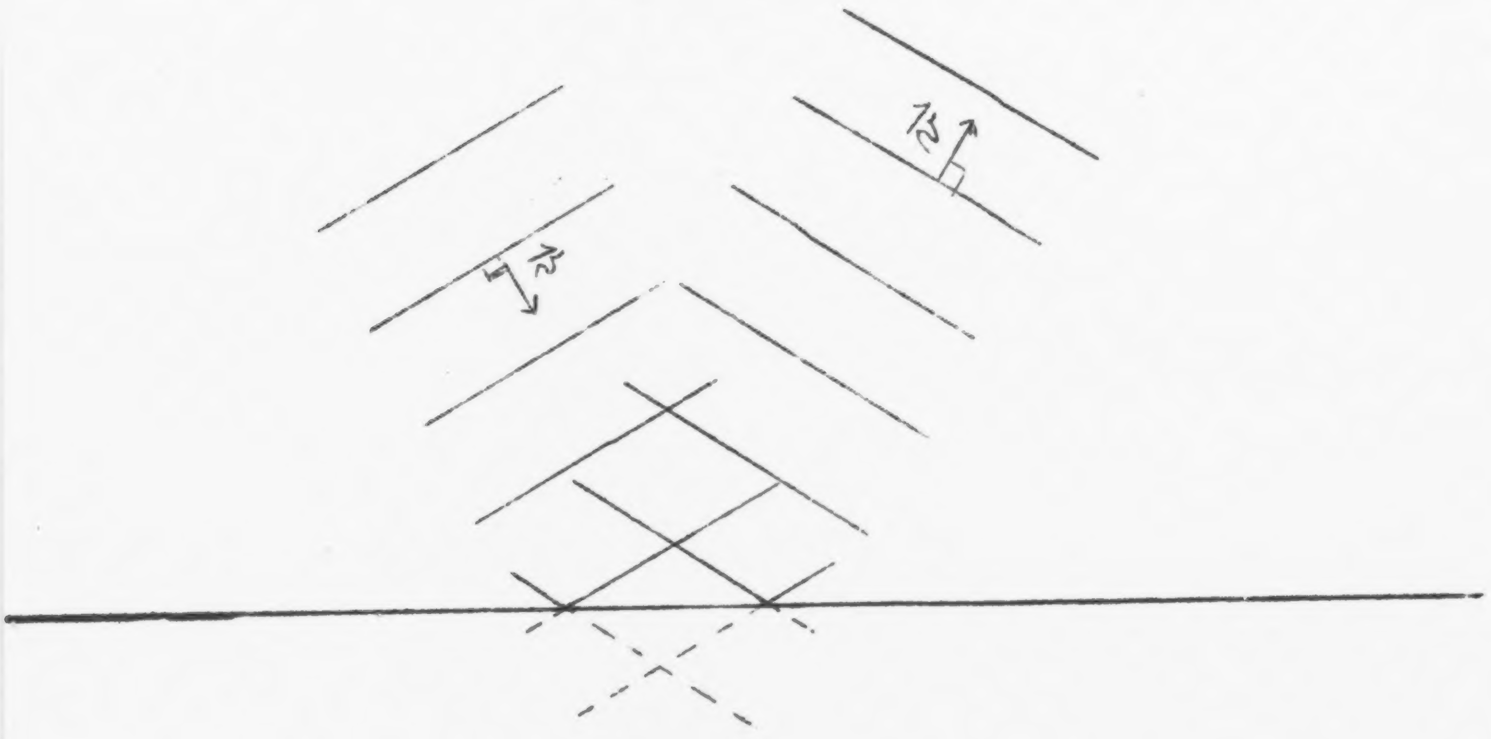
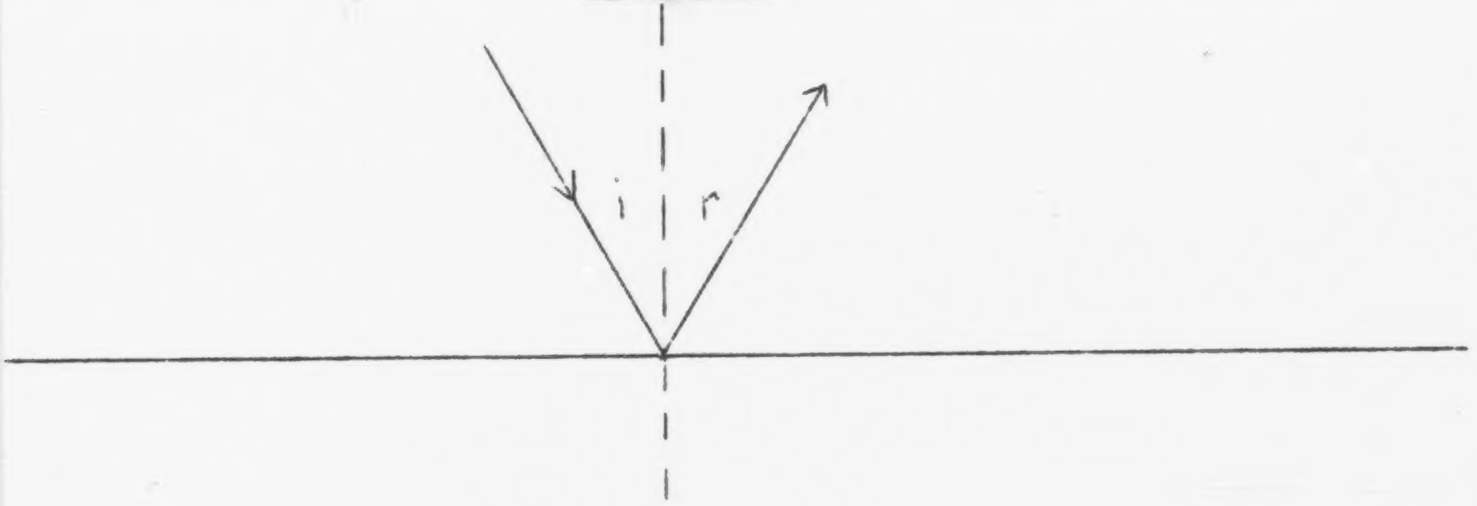


Figure 3b.



These diagrams show how a wave model can explain reflection.

All parts of one of these wave pulses travel with the same speed when in the same medium. When they are reflected, they remain in the same medium with the same speed, although their direction of propagation changes. Thus, a straight pulse goes out just as far in its new direction as it would have continued in its old direction ~~as it would have continued in its old direction~~ if there were no interface.

Hence, construction 3a above.

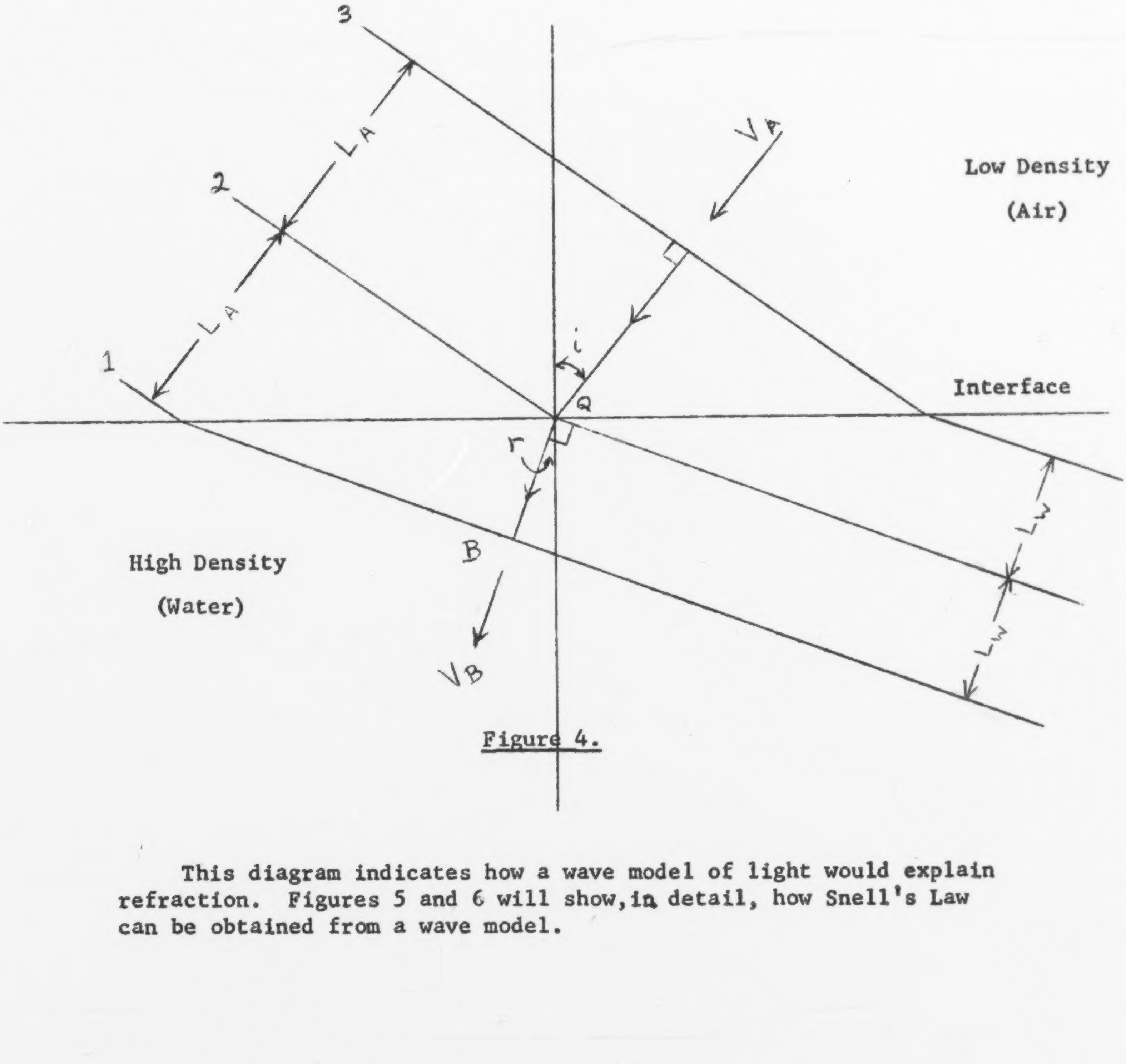

3
2
1
LA
LA
VA
Low Density
(Air)
Interface
i
Q
r
B
High Density
(Water)
VB
LW
LW

Figure 4.

This diagram indicates how a wave model of light would explain refraction. Figures 5 and 6 will show, in detail, how Snell's Law can be obtained from a wave model.

Figure 5

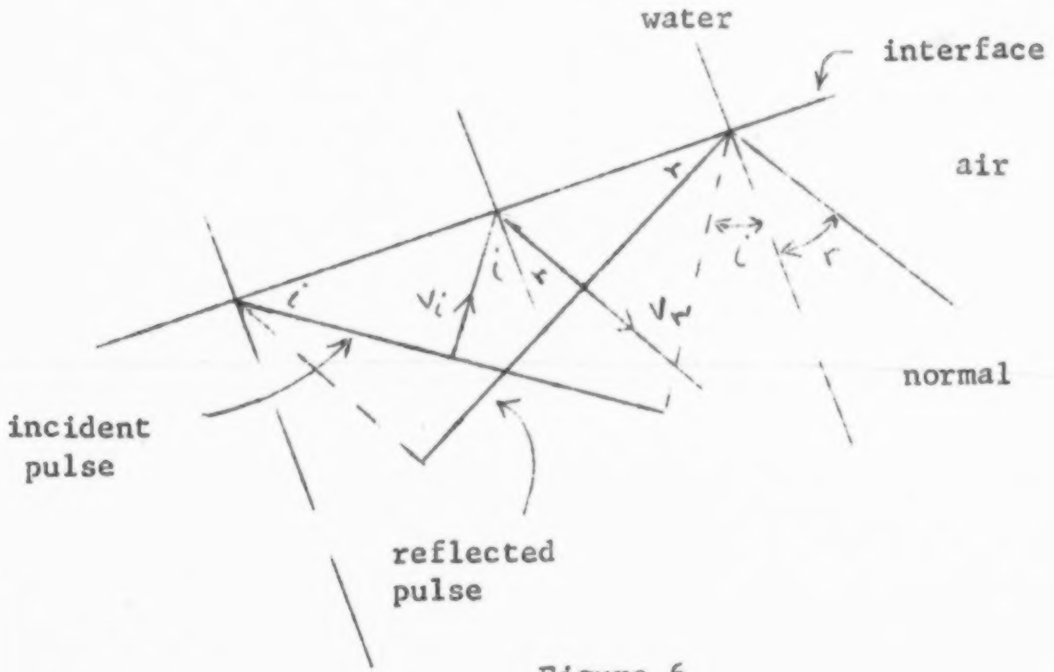

water
interface
air
r
i
V_i
V_r
i
r
normal
incident pulse
reflected pulse

Figure 6

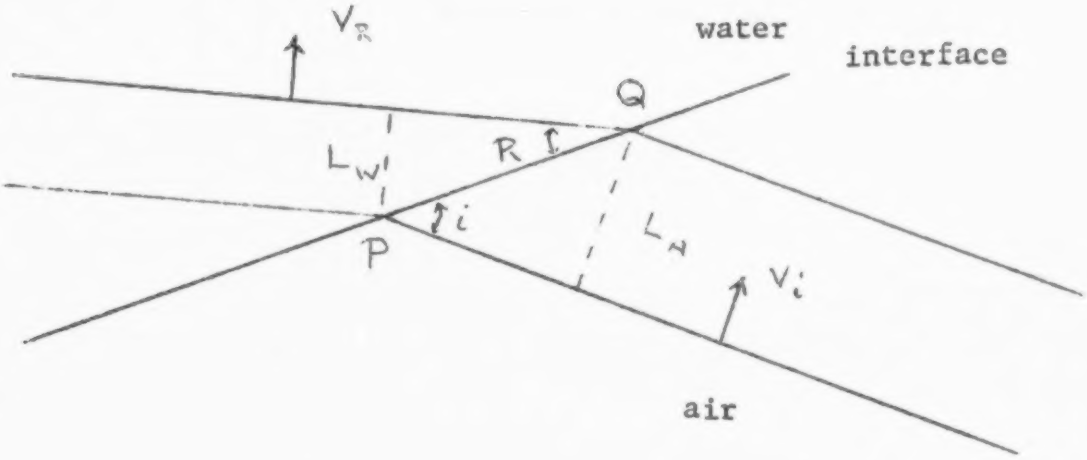

V_R
water
interface
Q
R
L_W
i
P
L_A
V_i
air

Figure 6 refers to the angle of refraction as R. Most other sources refer to both angles of reflection and refraction as r, leaving it to the student to determine which is intended, depending on the context.

Derivation of Snell's Law

Figure 5 shows that the angle between the incident ray and the ~~ar~~ normal to the surface is equal to the angle between the incident wavefront and the surface itself. Both have been labeled i in figure 5. The identical angle has also been labeled i in figure 6.

Since the refracted rays are also perpendicular to the refracted wavepulses and the normal on the denser side of the interface is also perpendicular to the interface, the same argument as shown in figure 5 proves that the angle labeled R in figure 6 is equal in size to the angle of refraction.

From figure 6:

$$\sin i = \frac{L_A}{PQ} \quad , \quad \sin R = \frac{L_W}{PQ}$$

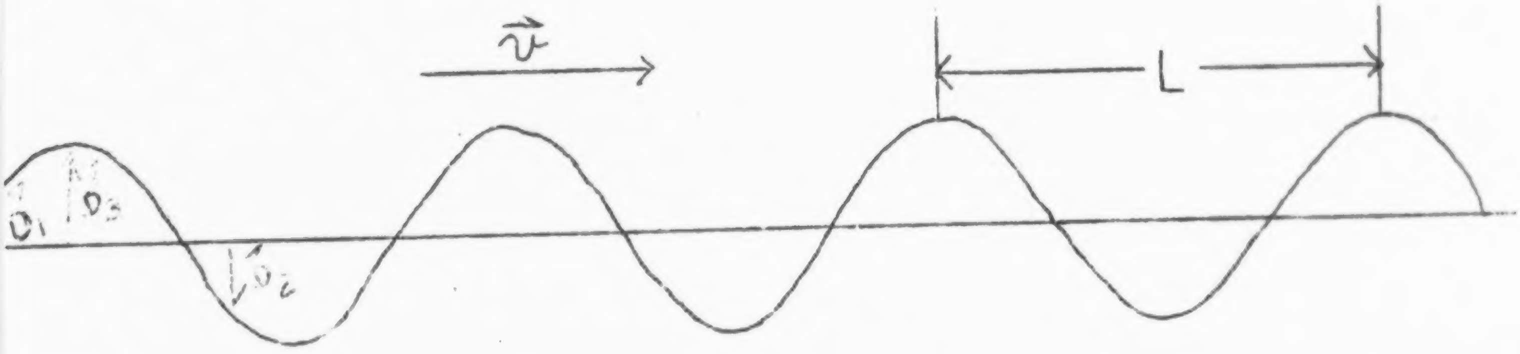
$$\frac{\sin i}{\sin R} = \frac{L_A}{L_W} = \text{constant (Snell's Law)}$$

$$\frac{\sin i}{\sin R} = \frac{L_A}{L_W} = \frac{V_A/f}{V_W/f} = \frac{V_A}{V_W}$$

This last equation correctly predicts that the velocity of light in air is greater than the velocity of light in water, since i is greater than R.

Outline of Lecture 9a

Figure 1.



A periodic wave has:

- frequency - f
- wavelength - L
- velocity - $\vec{v}$
- amplitude - A
- various displacement vectors - $\vec{D}$
  - note that $D_3 = A$

The superposition principle describes the behavior of two or more waves at the same place. It says that displacement vectors at the same location are additive.

Figure 2.

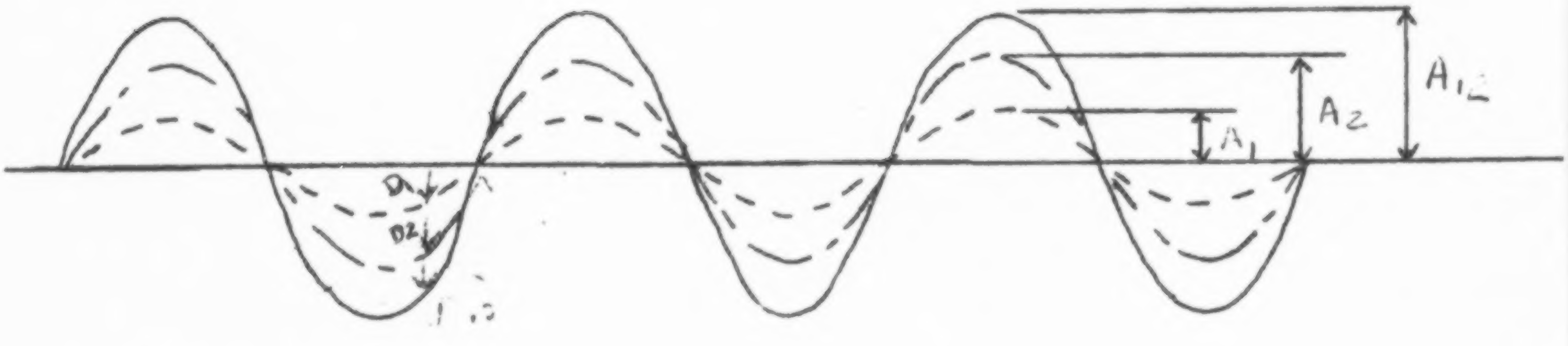

D1
D2
A1
A2
A1,2

Figure 2 shows two waves which are in phase and interfere constructively.

Figure 3.

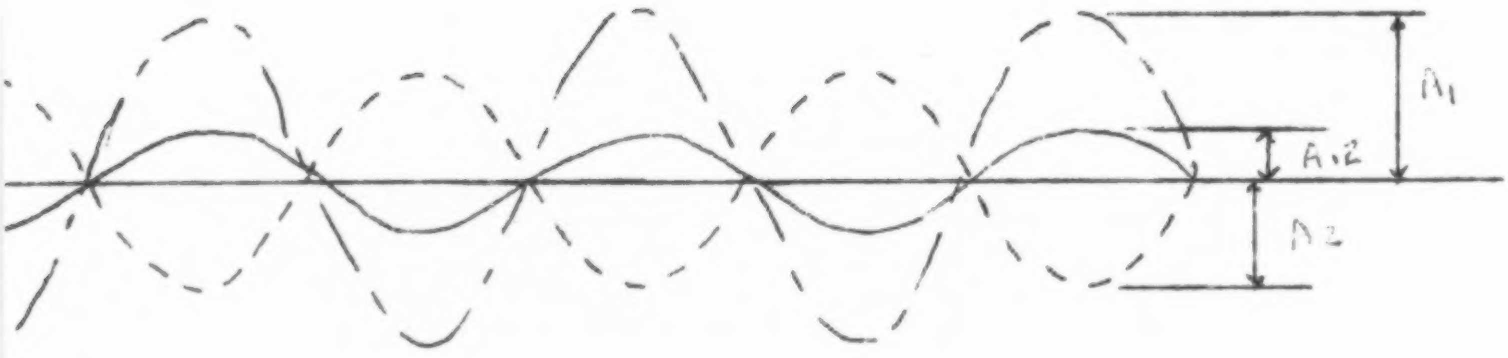


Figure 3, shows the opposite case. One crest is (1/2)L behind the other. The waves are interfering destructively. Since A_1 is not equal to A_2, complete cancellation does not occur.

Figure 4.

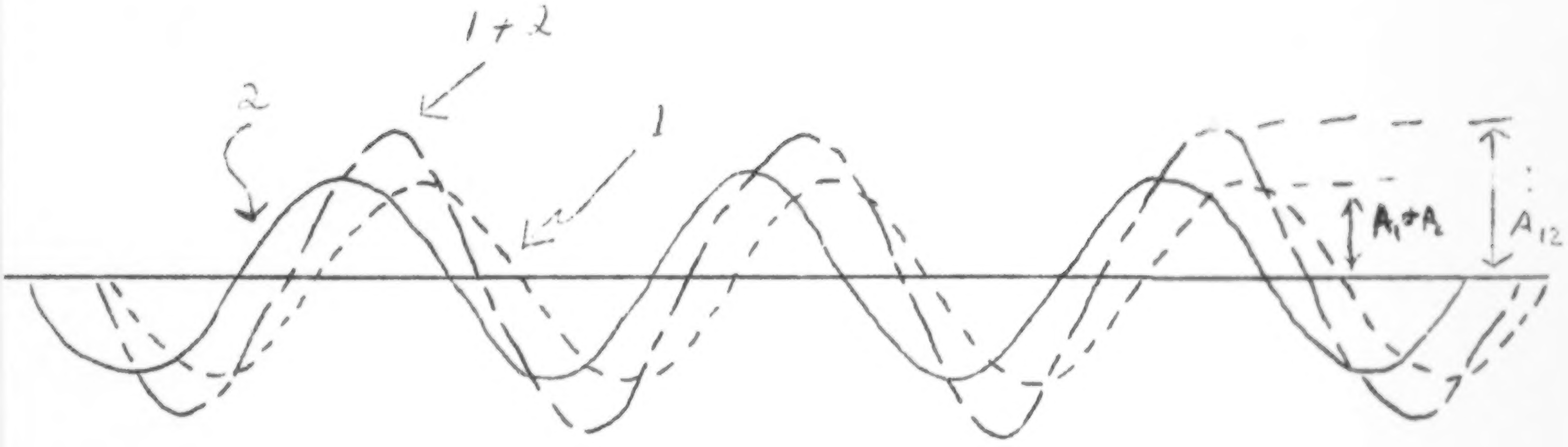
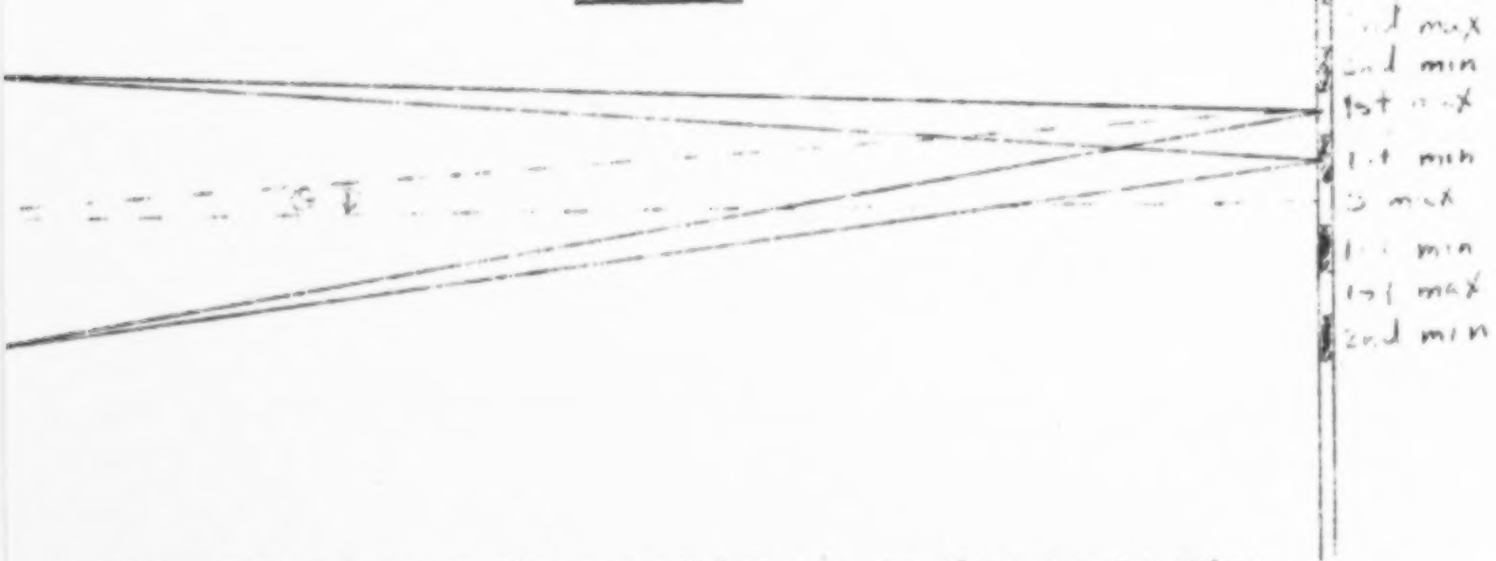


Figure 4 shows a representative example of two waves neither in phase nor completely out of phase. Note that:

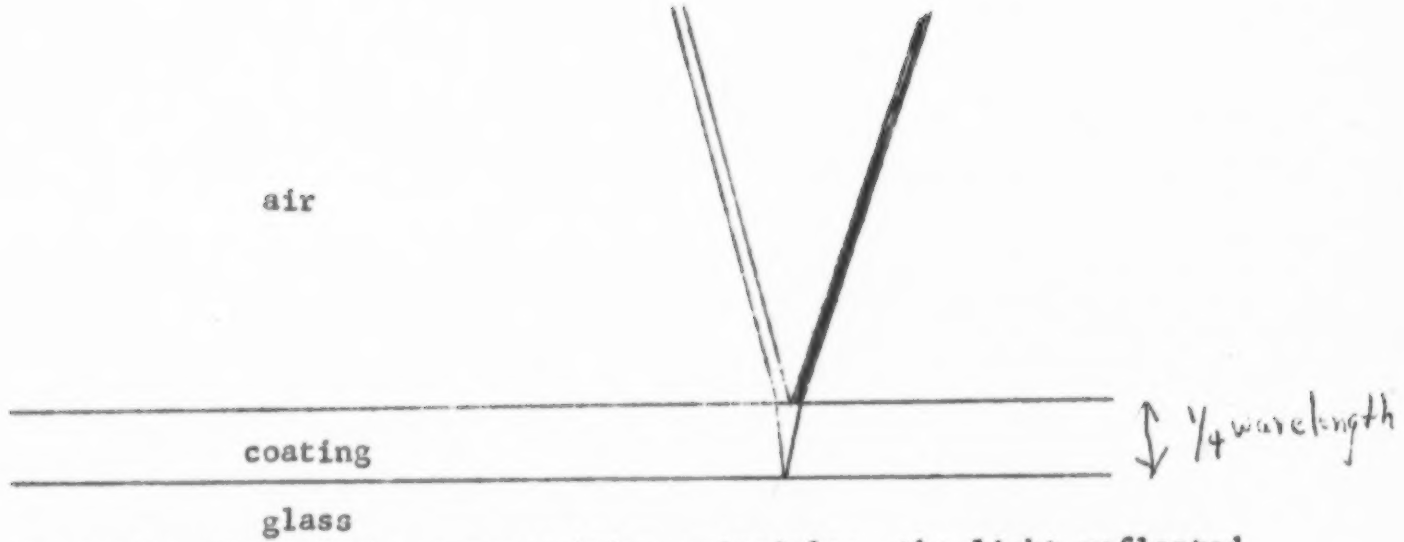
1. since they are closer to in phase than to completely out of phase, the resultant wave has larger amplitude than either of the others;
2. the resultant wave has the same wavelength, frequency, and velocity as the original two waves.
3. the two waves are of the same amplitude.

Figure 5.



These interference maxima and minima correspond to constructive and destructive interference. For example, the first bright band, or first maximum means that the wave from the lower slit has traveled one wavelength further than the wave from the upper slit so there is constructive interference there. The first minimum on top is where the wave from the lower slit has traveled 1/2 wavelength further than the one from the upper slit. There is complete destructive interference there.

Figure 6.



An application of the superposition principle: the light reflected from the bottom of the coating interferes destructively with the light reflected from the top of the coating. We don't see any green light reflected.

Figure 7.

Answer: No, this non-reflecting coating cannot be used. Since no green light would be reflected within the television, all of it would have to be transmitted. Since parts of the other kinds of light would be reflected, relatively less non-green light than green light would be transmitted. Your picture would be mostly green. This is not desirable unless you're watching a rerun of "The Wizard of Oz."

Outline to Lecture 9D

The equations which are derived from the wave model for light actually do describe these interference and diffraction patterns with complete accuracy.

We can now say that in as far as its propagation is concerned, light does act like a wave.

Figure 8.

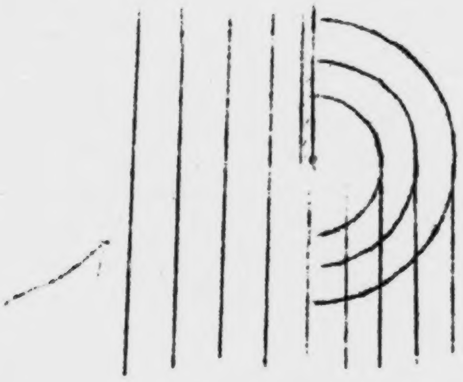


Figure 9.

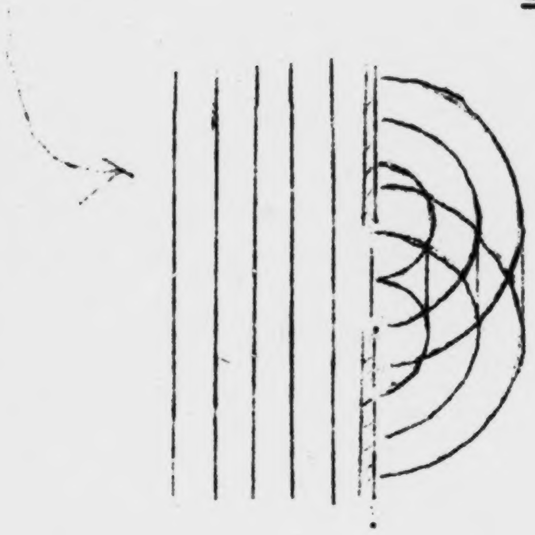


Figure 8 shows how flat waves are diffracted from one obstacle. Figure 9 shows diffraction by a single slit. In both cases, the film loop which shows the phenomenon will make it more clear than the diagram. These diagrams are just to show you what to look for in the film loops.

FILM NOTES

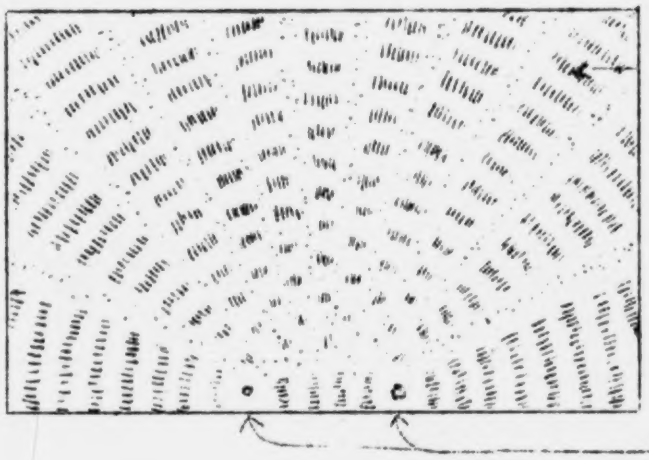
#80-241 EFFECT OF PHASE DIFFERENCES BETWEEN SOURCES IN A RIPPLE TANK

OBJECTIVE

To illustrate the effect of continuously varying the phase between two point sources.

DEMONSTRATION APPARATUS

Ripple Tank
overhead view



about one inch water

point sources with device for continuous phase shifting

BASIC THEORY

In two dimensions, e.g., on a water surface, a vibrating point source generates a circular wave pattern which steadily progresses outward. If two sources are vibrating in phase, an interference pattern is produced as indicated in the figure above. The dashed lines represent regions in which the water is always at rest due to the two waves always being one-half wavelength out of phase along these lines. These lines appear gray on photographing and they are the best regions to watch as the phase difference between the sources is changed.

To complete the picture briefly, regions of mostly-constructive interference will be between the gray lines and are indicated by the band regions. This region will progress outward as the individual waves propagate outwards.

FILM NOTES

#80-206 DIFFRACTION: SINGLE-SLIT

OBJECTIVE

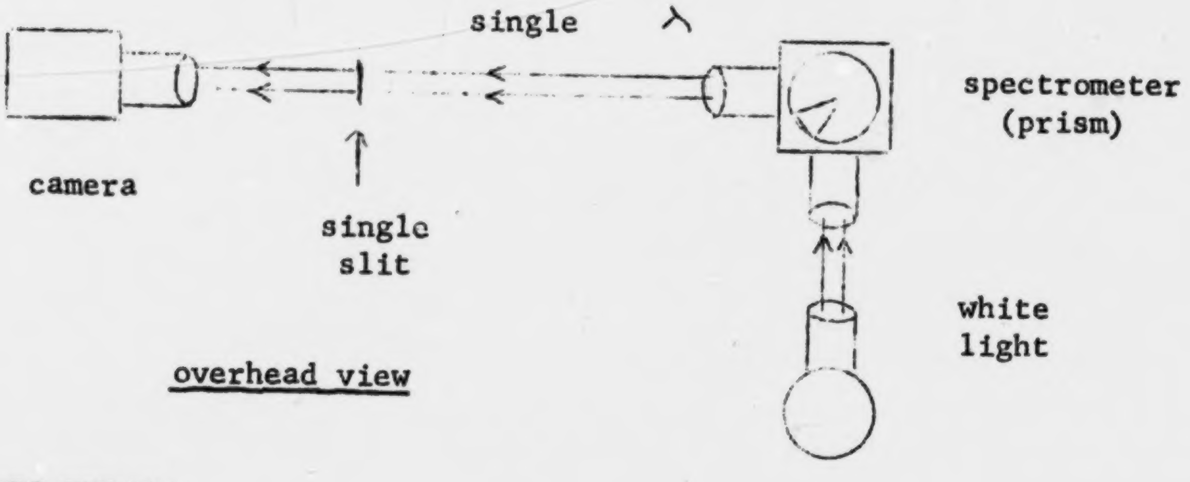
To illustrate the single-slit diffraction pattern.

DEMONSTRATION APPARATUS

A wavelength spectrometer is used to provide a narrow band of wavelengths which illuminate the single-slit. The camera is focused on the light from the spectrometer.

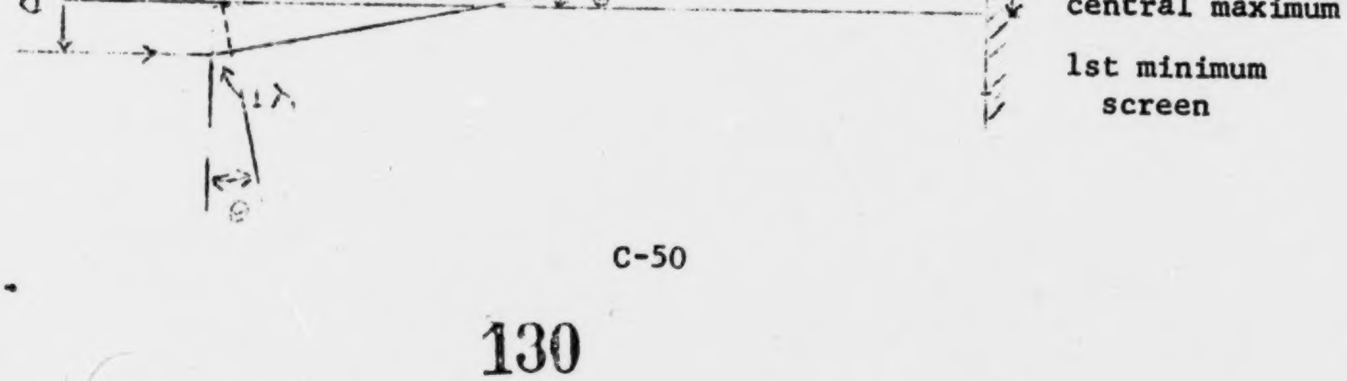
The single slit is obtained by placing a horizontal opening in front of a V-shaped pair of lines on photographic film. Moving the lines up and down in front of the horizontal opening provides slit-separation distances continuously from 0 to 0.024 inches.

The lines are only 0.004 inches wide.

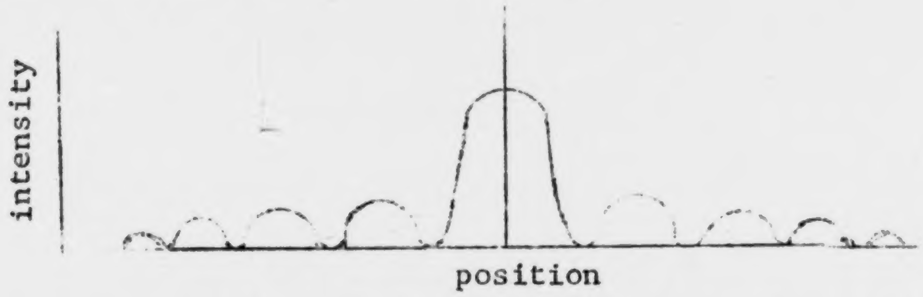

single λ
spectrometer (prism)
camera
single slit
white light
overhead view

BASIC THEORY

The requirement for the first minimum is indicated in the sketch below:


λ
d
θ
y'
$\frac{1}{2}\lambda$
θ
1st minimum
central maximum
1st minimum
screen

The intensity of the light on the screen for all of the pattern is indicated in the following sketch:



We see that most of the light is in the central maximum region.

The equation which relates the quantities for the first minimum is:

$$\sin \theta = \frac{\lambda}{d}$$

We see that for no diffraction, d. For a lot of diffraction, d.

For a given slit width, a smaller wavelength will yield less diffraction.

DEMONSTRATION PROCEDURE

1 Dependence on slit width. Using green light

(X = 5300 x 10^{-8} cm) diffraction patterns for d = 0.2 mm and 0.5 mm are compared. The centers of the patter appear white because of the necessity of overexposing the film.

We see that for the same , a smaller d yields greater diffraction.

2 Variable slit width. The slit is changed from 0 to 2 mm and back to 0. Green light is used.

Note that when the slit is widest, no diffraction minima are seen. The pattern is the geometric image of the source (the exit slit of the spectrometer).

3 Pattern depends on wavelength. Patterns are compared for red light (6500 x 10^{-8} cm) and blue light (4700 x 10^{-8} cm).

4 Variable wavelength. The wavelength is varied continuously from 6500 x 10^{-8} cm to 4700 x 10^{-8} cm and back again.

CONCLUSION

What has this demonstration taught you about single-slit diffraction?

FILM NOTES

#80-207 DOUBLE SLIT

OBJECTIVE

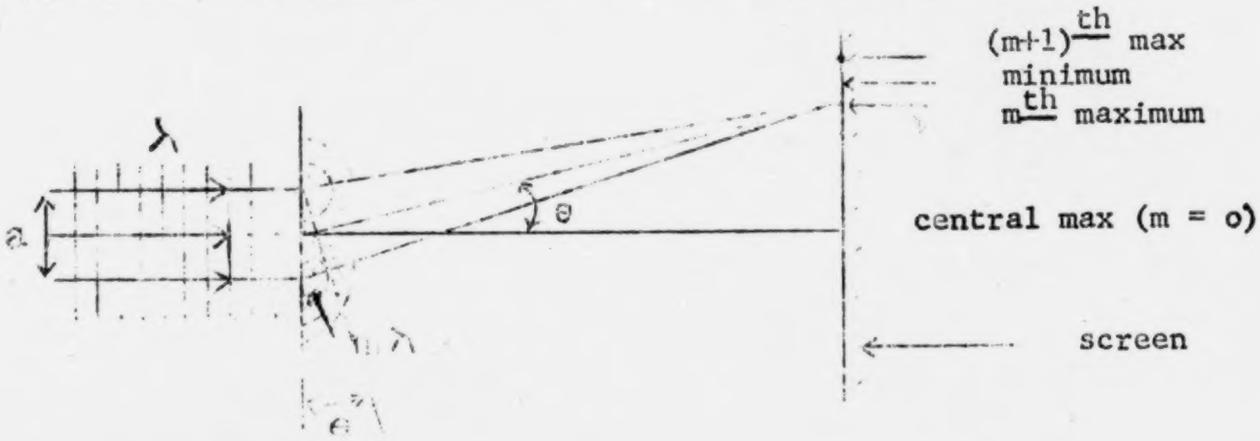
To illustrate the double-slit interference pattern for light.

BASIC THEORY

The double-slit interference pattern is a set of equally spaced maxima given by

$$\sin \theta = \frac{m\lambda}{a} \qquad (m = 0, \pm 1, \pm 2, \ldots)$$

where λ is the wavelength and θ and "a" are indicated on the sketch below.



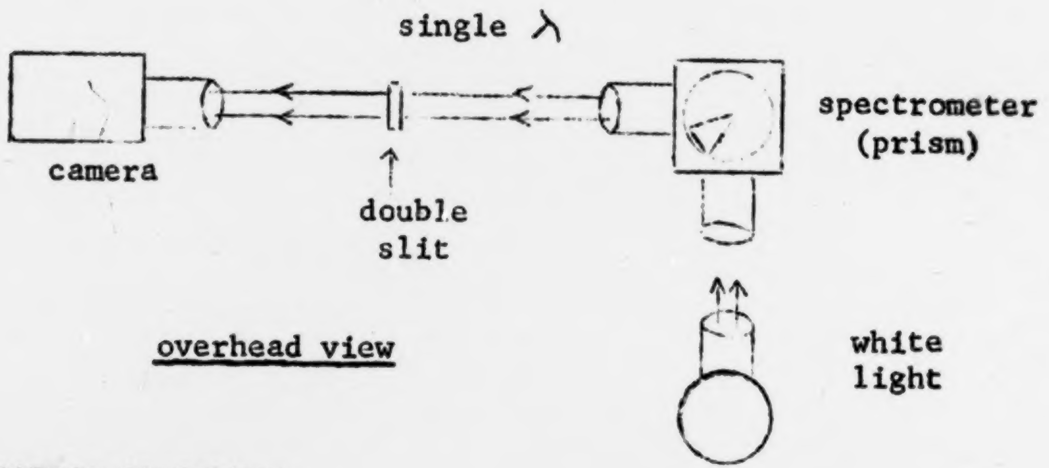
DEMONSTRATION APPARATUS

A wavelength spectrometer is used to provide a narrow band of wavelengths which illuminate the double-slit. The camera is focused on the light from the spectrometer.

The double-slit is obtained by placing a horizontal opening in front of a V-shaped pair of lines on photographic film. Moving the lines up and down in front of the horizontal opening provdes slit separation distances continuously from 0 to 0.024 inches.

The lines are only 0.004 inches wide.

(see sketch on next page)



DEMONSTRATION PROCEDURE

1 The dependence of the pattern on slit separation distance is shown. For $\lambda = 5300 \times 10^{-8}$ cm (green), the pattern for a "small" separation distance (a = 0.012 inch) and a "large" separation (a = 0.024 inch) are shown together for comparison.

Note that for a large "a", sin θ will be smaller for a particular m value and, therefore, the bands will be closer together.

The separation is changed from 0.008 inch to 0.024 inch and back again.

The appearance of the heavy dark bands in addition to the more numerous thin interference bands is due to single slit diffraction effects.

2 The dependence of the pattern on wavelength is shown for a fixed "a". Patterns for red (6500×10^{-8} cm) and blue (4700×10^{-8} cm) are shown together for comparison.

For a given m and "a", a smaller λ will yield a smaller θ. Therefore, the bands for blue will be spaced closer together.

3 Starting with red light, the effect of steadily changing the wavelength to blue and back again is demonstrated.

Note that as the wavelength becomes shorter the spacing of the bands becomes less.

FILM NOTES

#80-244 DIFFRACTION AND SCATTERING AROUND OBSTACLES IN A RIPPLE TANK

OBJECTIVE

To illustrate diffraction due to obstacles in the path of a flat wave.

DEMONSTRATION APPARATUS

A ripple tank with a variable frequency generator of flat waves.

DEMONSTRATION PROCEDURE

1 A flat wave is half-blocked by a straight barrier which is parallel to the wave crests.

Note that the wave bends into the region behind the barrier. This effect is called diffraction.

As the wavelength is made shorter, the diffraction effects are decreased, aren't they?

2 Diffraction of a wave around a small obstacle is shown. To start with, the wavelength is smaller than the obstacle.

The wavelength is increased until it is about the same as the obstacle. As the wavelength approaches the size of the obstacle, the diffraction effects (1) become greater, (2) become less, (3) remain the same?

Since diffraction has to do with the "bending" of waves around barriers, answer (1) is correct.

3 The wavelength is much larger than the obstacle in this case. The effect is called scattering rather than diffraction.

CONCLUSIONS

In your own words, what do you now know about diffraction?

DEMONSTRATION PROCEDURE

Note: The frequency, wavelength and source separation distance are kept constant throughout the demonstration.

1 At the start, the two sources are in phase and, therefore, the positions along the perpendicular bisector are of maximum constructive interference. The gray lines, showing regions of complete destructive interference lie on each side of this central maximum.

Then the right sources is steadily shifted in phase until it is one-half wavelength different from the other source. The perpendicular bisector region is now a gray line! The maxima and minima have exchanged positions.

2 Further shifting of the right source by one-half wavelength produces the original pattern.

The right source is shifted another half wavelength.

3 Now the right source is steadily shifted through several wavelengths so as to clearly observe the shifting pattern.

*Watch the beat effect at the marker. This effect is a pulsating change in the intensity at a given point. The gray region is of zero intensity and the radially progressing band regions are of maximum intensity.

The curving of the maximum and minimum here are due to the finite propagation speed of the waves.

CONCLUSION

In your own words, how does the shifting of phase between two point sources change the interference pattern?

---

*Optional

Outline of Lecture 10 on Forces

Force: a push or a pull, has both magnitude and direction so it is a vector quantity.

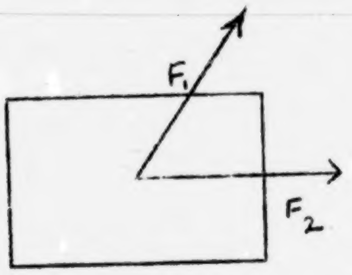


Figure 1a

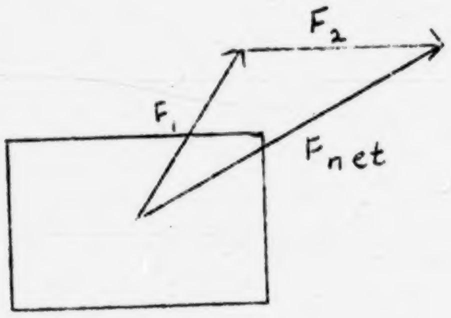


Figure 1b

If you push on an object with an unbalanced force, the object will accelerate. This acceleration will be proportional to the net unbalanced force acting on the object.

LESSON 11

Thus far, you have learned several things about forces. Let's quickly review them:

(1) Forces have magnitude and direction; therefore, they are vector quantities.

(2) A force is either a push or a pull.

(3) The resultant, or net force acting on an object is the vector sum of all the forces acting on the object, and the object responds as if only the net force were acting.

(4) If the net force is not zero, it will cause a change in motion in the direction of the force.

(5) If the net force is zero, no change in motion will occur. It is to be noted that every physical body has a certain point which has the property that if the net unbalanced force is applied at that point, we don't have to worry about the rotation of the body. This point is called ~~the~~ center of mass.

Now, we would like to see if we can find a relationship between the force acting on an object and how the object behaves under the action of that force. The film "Inertia" will develop such a relationship by studying the motion of an object experiencing various forces.

You will be given an opportunity to see for yourself how objects behave under the influence of zero net force, or of a single force (this part is repeated so you can see the effect produced by each of two individually applied forces of differing magnitudes), or of two forces applied in differing directions. These experiments must be carried out under nearly frictionless conditions, cleverly achieved by means of so-called "dry ice pucks" sliding over a smooth aluminum surface.

Ask the proctor for film 302, "Inertia." After you have viewed it, look over the following film review and then go back to your terminal for a short quiz covering its main points.

Film Review

In the film you just saw, several important ideas were presented:

I. If no net force acts on a body, the original state of motion is retained. If originally at rest, the object remains at rest; if originally in motion, the object continues to move in a straight line with constant speed. From reading your textbook, you should recognize the idea as Newton's first law.

II. The acceleration of a single body acted upon by two forces pointing in different directions is in the direction of the vector sum of the two forces. This idea is a demonstration of the vector nature of forces.

III. A constant unbalanced force produces uniform acceleration in the direction of the force.

IV. Doubling the force applied to an object doubles the observed acceleration.

These last two points suggest that the acceleration produced by an applied force is proportional to the force, or a is proportional to F. This is indeed the case. Notice that a and F are both vector quantities, and, therefore, a has the same direction as F. In the next lesson, you'll learn that even more can be said about the relationship between a and F. We'll save that for next time, however. Now, please report to your terminal.

Outline to Lecture 11B

I. Newton's first law: if no net force acts on a body, its original state of motion is retained.

II. The acceleration of a single body acted upon by two or more forces is in the direction of the vector sum of the forces.

III. A constant unbalanced force produces uniform acceleration in the direction of the force.

IV. $a \propto F$, and both are in the same direction.

#10 FUN AND GAMES USING INERTIA II

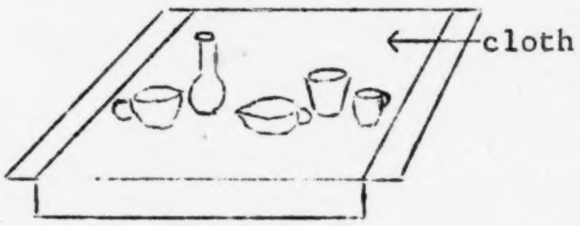
OBJECTIVE

To illustrate the principle of inertia.

BASIC THEORY

The Principle of Inertia: An object at rest (or uniform motion) tends to remain in that state unless a resultant force acts on the object.

DEMONSTRATION APPARATUS



DEMONSTRATION PROCEDURE

1 A quick jerk of the cloth and the objects essentially stay where they were.

This procedure is repeated.

The procedure is repeated again and observed from the side.

2 With a top view, the cloth is pulled slowly and the objects move along maintaining a steady upright position.

When the cloth is jerked, the objects stay where they were.

This procedure is repeated.

CONCLUSION

In your own words, how is the principle of inertia exemplified here?

FILM NOTES

#19 FUN AND GAMES USING INERTIA III

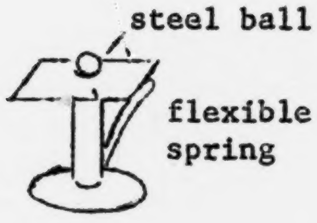
OBJECTIVE

To illustrate the principle of inertia.

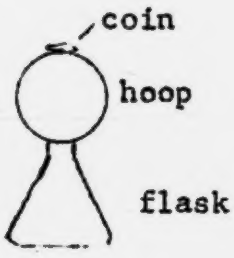
BASIC THEORY

The Principle of Inertia: An object at rest (or in uniform motion) tends to remain in that state.

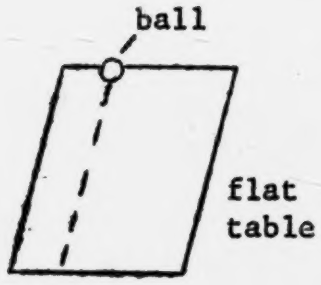
DEMONSTRATION APPARATUS



1



2



3

DEMONSTRATION PROCEDURE

1 The spring is pulled back and released. The steel ball remains on the cylindrical support!

2 The hoop is knocked sideways and the coin falls into the flask!

3 Steel balls are rolled across a flat table. According to the principle of inertia, they should roll in a straight line - unless a resultant sideways force acts on the ball.

If there is a resultant sideways force, the ball will show you!

CONCLUSION

How is the principle of inertia illustrated in each of these cases?

Outline to Lecture 12

$a \propto 1/m$ a = acceleration

m = inertial mass

$a \propto F$ F = force

so, $a \propto (F) \times (1/m)$

or, $a \propto F/m$

or, $F \propto ma$

$F = ma$ if F is measured in kg - m/sec^2 or newtons.

Weight = gravitational force acting on object of mass, m.

$W = mg$ where g = acceleration of gravity.

The gravitational acceleration, g, of an object due to another object depends upon the distance of separation of the objects as well as their masses.

For a falling body in the earth's atmosphere:

$$F_{net} = W - F_{air\ resistance}$$

$$ma = mg - F_{air\ resistance}$$

$$a = \frac{mg - F_{air\ resistance}}{m}$$

If we are in a vacuum,

$$F_{air\ resistance} = 0$$

$$a = \frac{mg - 0}{m} = g$$

All masses experience the same acceleration due to gravity if they are in the same location relative to the earth, and we can ignore air resistance.

Near the surface of the earth, g is about 9.8 m/sec^2.

Outline to Lecture 13A

Motion in a curved path.

Recall: velocity is a vector quantity = rate of change of displacement with respect to time;

acceleration is a vector quantity = rate of change of velocity with respect to time.

But velocity will change if either the speed or the direction changes, so there can be an acceleration for which the speed doesn't change.

Deflecting force = the component of force perpendicular to the velocity at a given instant.

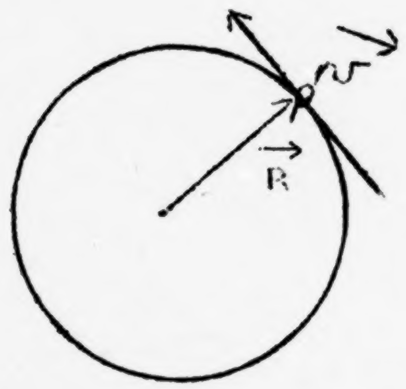
If the speed of an object does not change, but its direction changes uniformly, the object moves in a circle.

Outline, Lecture 13B

Uniform Circular Motion

Figure 1.

particle of mass m
revolving about center o

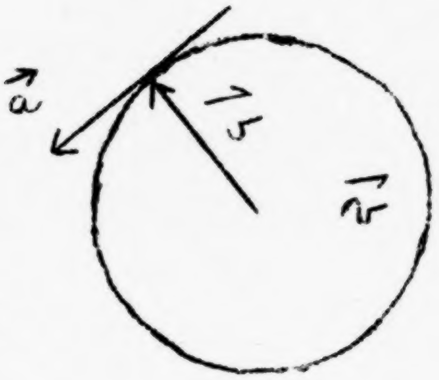


velocity, $\vec{v}$, is perpendicular to $\vec{R}$

$$\text{speed } v = \frac{\text{circumference}}{\text{time for one rotation}} = \frac{2\pi R}{T}$$

or, $v = \frac{2\pi R}{T}$ where T is period of rotation

Figure 2.



acceleration a is perpendicular to v

magnitude of acceleration a = $\dfrac{\text{circumference}}{\text{time for one rotation}}$

$$a = \frac{2\pi v}{T} = \frac{2\pi}{T}\left(\frac{2\pi R}{T}\right) = \frac{4\pi^2 R}{T^2}$$

It is also true that: $a = \dfrac{v^2}{R}$

because, $a = \dfrac{2\pi v}{T} = 2\pi v\left(\dfrac{v}{2\pi R}\right) = \dfrac{v^2}{R}$

and so, $F_{\text{centripetal}} = ma = \dfrac{4m\pi^2 R}{T^2} = \dfrac{mv^2}{R}$

Note that this derivation depended upon the property of vectors that allows one to be moved anywhere as long as its direction and magnitude remain the same. The point at which the velocity vector touches the circle in Figure 1 moves with time. But in Figure 2, all the directions at which the vector, v, points during its trip around the circumference are covered byathe same vector, v, which now has a non-moving origin.

Outline of Lesson 14

Planets move in such a way that both their speed and direction are continuously changing. Thus, by Newton's Law, a net force must be acting upon them.

Newton postulated that the relevant force was a force of attraction between the sun and each planet.

He postulated that the force on one point particle of mass m_1, due to a point particle of mass m_2, is:

$$F = \frac{Gm_1m_2}{r^2}$$

where r is the distance between the particles

and G is the universal gravitational constant.

Lesson 14, Continued

Eq. 1 centripetal acceleration $a = \frac{v^2}{r}$

r = radius of orbit

v = speed of satellite

Eq. 2 $ma = \frac{mv^2}{r}$

Eq. 3 $F = mg$

Since $F = ma$

Eq. 4 $mg = \frac{mv^2}{r}$

Dividing through by m

Eq. 5 $g = v^2/r$

Eq. 6 $v^2 = gr$

Example of calculation of a satellite's speed and period of revolution

$v^2 = gr$

$g = 8.6\ m/sec^2$ at this r

$r = 400$ km. + radius of earth $= 6.8 \times 10^6$ meters

$v^2 = (8.6)(6.8 \times 10^6)\ m^2/sec^2$

$v = 7.6 \times 10^3\ m/sec$

$2\pi r = v\ T$

$T = 2\pi r/v$

$$= \frac{(2\pi)(6.8 \times 10^6 m)}{7.6 \times 10^3\ m/sec} = 5.6 \times 10^3 \text{ sec.} = 93 \text{ minutes}$$

Outline to Lesson 15

$$\vec{F} = ma = m\frac{\Delta v}{\Delta t}$$

or

$\vec{F}\Delta t = m\Delta\vec{v} = \Delta(m\vec{v})$ where $m\vec{v}$ is called momentum.

Impulse = change in momentum

Lesson 15 continued

Derivation of the law of conservation of momentum

$$\vec{F}_1 \Delta t = -\vec{F}_2 \Delta t$$

$$\vec{F}_1 \Delta t = m_1 \Delta \vec{v}_1$$

$$\vec{F}_2 \Delta t = m_2 \Delta \vec{v}_2$$

$$m_1 \Delta \vec{v}_1 = -m_2 \Delta \vec{v}_2$$

$$\Delta \vec{v}_1 = \vec{v}_1' - \vec{v}_1 \quad , \quad \Delta \vec{v}_2 = \vec{v}_2' - \vec{v}_2$$

substituting these in Eq. 3

$$m_1 (\vec{v}_1' - \vec{v}_1) = -m_2 (v_2' - \vec{v}_2)$$

$$m_1 \vec{v}_1' - m_1 \vec{v}_1 = -m_2 \overset{\rightarrow\prime}{v2} + m_2 \vec{v}_2$$

$$m_1 \vec{v}_1' + m_2 \vec{v}_2 = m_1 \vec{v}_1 + m_2 \vec{v}_2$$

This is one expression for the Conservation of Momentum. An alternate one is

$$\vec{P}_1 + \vec{P}_2 = \vec{P}_1 \div \vec{P}_2$$

$P = P'$ (P before = P after)

or $P' - P = o$

$\Delta P = o$

#38 CONSERVATION OF LENEAR MOMENTUM: ROCKET EXPERIMENT

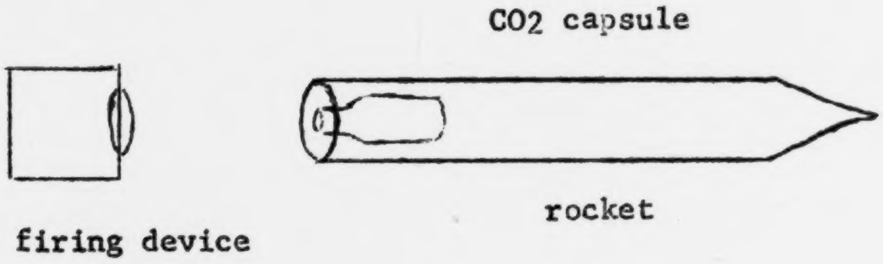
OBJECTIVE

To illustrate the conservation of linear momentum.

BASIC THEORY

From momentum conservation, a rocket which is initially at rest has zero momentum. If material is ejected with a momentum in the backward direction, then the rocket must have an equal forward momentum. The continual ejection of μ kg/sec (or slug/sec) at a speed of u m/sec (or ft/sec) constitutes a thrust on the rocket of μ u newtons (or pounds).

DEMONSTRATION APPARATUS



DEMONSTRATION PROCEDURE

1 The rocket, CO_2 capsule, and firing mechanism is shown. The capsule is placed in the rocket.

2 The rocket is fired several times and looked at from a side view and a rear view.

CONCLUSION

In your own words, how does this demonstration illustrate momentum conservation?

Outline to Lecture 16

Work is a precise measure of energy transfer.

Work = the component of the applied force along the direction of motion times the distance moved.

Eq. 1 $W = F_x \cdot x$ where x is the distance moved and F_x is the component of force in the x direction.

If the force and the displacement are in the same direction, our equation is:

$$W = \vec{F} \times \vec{d}$$

Lecture 16 - Continued

Eq. 2 $F = ma = \text{constant}$

Eq. 3 $W = Fd = mad$

Eq. 4 $d = \bar{v}t = \frac{v_1 + v}{2} t$

where v is final velocity

v_1 is initial velocity

$\bar{v}$ = average velocity

Eq. 5 $a = \frac{v - v_1}{t}$

Eq. 6 $d = (1/2)\, vt$

and $a = \frac{v}{t}$ since $v_1 = 0$.

Eq. 7 $W = mad = m \times \frac{v}{t} \times (1/2)\, vt = (1/2)\, mv^2$

Eq. 8 $\boxed{KE = (1/2)\, mv^2}$

Kinetic energy depends only on the body's mass and present speed.

Eq. 9 1 joule = 1 newton-meter = 1 kg m^2/sec^2

Lesson 16 - Continued

Eq. 10 $m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$

Elastic Collision: kinetic energy as well as momentum is conserved.

Eq. 11 $1/2\ m_1v_1^2 + 1/2\ m_2v_2^2 = 1/2\ m_1v_1'^2 + 1/2\ m_2v_2'^2$

Eq. 12 $\frac{m_1-m_2}{m_1+m_2} \times v_1$

Eq. 13 $v_2' = \frac{2m_1}{m_1+m_2} \times v_1$

Eq. 14 $v_1' = \frac{m-m}{m+m} \times v_1 = \frac{0}{2m} \times v_1 = 0$

Eq. 15 $v_2' = \frac{2m}{m + m} \times v_1 = v_1$

(**Equations** 14 and 15 apply if masses m_1 and m_2 are equal.)

#31 CONSERVATION OF LINEAR MOMENTUM: BILLIARD BALLS

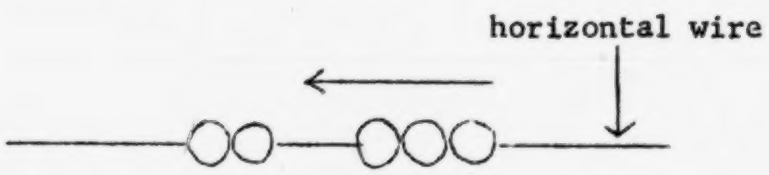
OBJECTIVE

To illustrate the conservation of linear momentum.

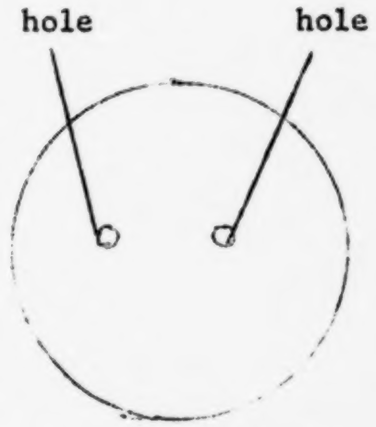
BASIC THEORY

The Conservation of Linear Momentum: If no external forces act on a system, then momentum must be conserved.

DEMONSTRATION APPARATUS



hard spheres on a wire



end view (enlarged)

DEMONSTRATION PROCEDURE *

The following cases are illustrated:

1 One colliding with one initially at rest.

2 One " " two " " "

3 Two " " two " " "

4 Three " " two " " "

5 Four " " one " " "

6 One on one, etc., with putty placed on one

7 One on four, with position indicators set up

8 One on one with position indicators set up

*Billiard balls with two small holes drilled through them are strung on two steel wires so that they can slide freely and can collide with each other. A series of experiments are performed, with a different number of balls being given an initial speed and letting them collide with other balls.

CONCLUSION

Write down, in your own words, your conclusions.

Outline to Lecture 17

Potential Energy

Work done in lifting an object to the height h from the ground is

$$W = F \times d = mg \times h.$$

If we now let the object fall from h to the ground just before it hits the ground, it will have a velocity v_{final} and, so, a kinetic energy $1/2\ mv^2_{final}$. This kinetic energy in joules ought to be just equal to the amount of work done in joules by the force which lifted the object. So this quantity of joules was expended to get the object up to h, and the object has the quantity of joules as kinetic energy at the end of its fall. It seems that the object must have somehow retained these joules at the time when the force had stopped pushing the object up, just before it started to fall. We say that at this point, these joules were the object's potential energy. We give it this name because the joules at this time have the potential to increase the object's kinetic energy. As it falls, we say that it loses just as much potential energy as it gains kinetic energy.

Eq. 1 $W_{fall} = mgh = 1/2mv^2_{final}$

Eq. 2 $(PE)_{initial} = (KE)_{final}$

for an object which falls from rest at height h.

In the more general case:

Eq. 3 $(PE)_{initial} + (KE)_{initial}$

$= (PE)_{final} + (KE)_{final} = \text{constant}$

This is the equation of conservation of mechanical energy for an object which has any initial velocity and falls for any distance.

You should see how Eq. 2 is a special case of Eq. 3.

Eq. 4 $(PE)_i + (KE)_i = (PE)_f + (KE)_f$

Eq. 5 $mgh + o = o + 1/2mv^2_f$

so $gh = 1/2v^2_f$

$v^2_f = 2gh$

$v_f = \sqrt{2gh}$

Example: If h = 10 meters, then

$v_f = \sqrt{2 \times 9.8m/sec^2 \times 10m}$

$= \sqrt{196\frac{m^2}{sec^2}} = 14m/sec$

NOTE: We arbitrarily assigned zero potential energy to the ground level in our examples above. We did this for simplicity, since we expected the object to hit the ground and stop.

If there were a hole in the ground, the object would continue to fall and to gain even more kinetic energy until it hit the bottom of the hole. Then there would be no advantage to assigning zero potential energy to ground level. Instead, we would call the potential energy at the bottom of the hole zero. We introduced the concept of potential energy so that we could write an equation for conservation of energy.

But this equation will hold for any original potential energy as long as the changes in potential energy are consistent with the changes in kinetic energy. So, you can choose your zero for potential energy to be anything you want, like the ground.

Lesson 18 - Conservation of Energy

n our first example of performing work, lesson 16, a force was applied to an which was free of all other forces and the result was that it gained kinetic , $W = 1/2\ mv^2$. In a further example, lesson 17, work was done on an object the influence of gravity in the act of lifting it. In this case, the object potential energy, $W = mgh$. This potential energy could be converted back to c energy, without energy loss, if the object was allowed to fall. Total ical energy, PE + KE, was conserved.

et us now consider a third example, that of slowly pushing a heavy box across oor by exerting a horizontal force. The amount of work performed is given F x d, (work equals force times distance). If you push just hard enough to he box moving, there is no increase in kinetic energy. Also, if you stop g and let go, the box remains motionless. That is, the box has not gained any ial energy or kinetic energy. What happened to the work which was performed? swer is that due to the friction between the box and the floor, heat has been ted and the box and floor are slightly warmer than before. Heat is another of energy. In this case, the work has produced heat energy rather than ical energy as in the two previous examples.

riction is not the best way to produce heat energy if it is heat energy you As you know, it is harder to get warm by rubbing your hands together than it lighting a fire. When the wood burns, the chemical potential energy is released converted into heat energy. Heat energy can in turn be converted into ical energy through the use of a steam engine.

ometimes the conversion of energy from one form to another is not 100% efficient. ample, the exhaust of a steam engine is hot steam which is released into the d thus not all the heat energy is converted into mechanical energy as we might In fact, in adding up energy transfer, three medhods of transfer must be kept in mind: mechanical work, heat flow, and radiation. The total energy, however, is always constant in the conversion of energy from one form to others, if you are careful to add in all forms of energy. This fact is vividly demonstrated in the film "Conservation of Energy". In this film, the idea of conservation of energy is presented in a highly quantitative way. You'll be taken on a "tour" through an electric power plant and shown the processes whereby chemical energy stored in the coal is changed to heat energy in the form of steam; the heat energy is changed to mechanical energy of the moving turbine; and finally, the mechanical energy is changed to electrical energy from the generator.

Report to your terminal for a lecture quiz.

Outline to Lecture 18

eat: another form of energy. However, it is not mechanical energy.

or a box being pushed along the floor:

$$(KE)_{initial} + (PE)_{initial} =$$

$$(KE)_{final} + (PE)_{final} + E_{dissipated\ due\ to\ friction}\ (heat)$$

OTE: In this case $(PE)_i = (PE)_f$

hen

$$(KE)_{initial} = (KE)_{final} + E_{dissipated\ due\ to\ friction}$$

quation One is a more general statement of conservation of energy than on 3 in Lecture 17. That equation took into account only the total mechanical (potential plus kinetic).

Outline to Lecture 19

Statement A: Like electric charges repel. Unlike charges attract.

The force of attraction or repulsion between electric charges depends only upon the size and sign of the charges and the distance between them.

To be specific, the rule is:

$$F = \frac{KQ_1Q_2}{R^2} \qquad \text{(Coulomb's Law)}$$

where Q_1 is the size of the first charge

Q_2 is the size of the second charge

R is the distance between them

K is an experimentally determined constant.

The signs of Q_1 and Q_2 determine whether the force is attractive or repulsive.

If we agree on one thing (namely, that positive forces are repulsive, minus forces are attractive), statement A, above, is built into Coulomb's Law.

If sign of Q_1 is	And sign of Q_2 is	Sign of the product Q_1Q_2 is	Sign of F is	F is
+	+	+	+	repulsive
-	-	+	+	repulsive
-	+	-	-	attractive
+	-	-	-	attractive

Lesson 20 - Electrostatics

Lecture 20, using film loops nos. 281, 283, 290

In the last lesson you saw a film about Coulomb's law, which demonstrated that e mathematical expression for the force between two charged bodies is an inverse uare law; that is, the force is inversely proportional to the square of the dis- nce between them, and the force acts along the line between the bodies. Electri- l forces are sometimes attractive, sometimes repulsive, as was pointed out in cture 19.

We mentioned, too, that glass rods which have been rubbed with silk exert rces of repulsion on each other. Also, rubber rods which have been rubbed with r repel each other, but the rubbed glass rod ATTRACTS the rubbed rubber rod. is seems to indicate that there must be different kinds of electricity, a fact at has been known for centuries.

Some demonstrations of these forces are given in the film loop 80-281 ntroduction to Electrostatics". Let me describe, briefly, what's in the film fore you go look at it.

First you'll see that when a piece of plastic, rubbed with a cloth, is held er a pile of light, uncharged particles, they jump up to the plastic. The slow- tion movie demonstrates something we've heard before about the relative strength electric and gravitational forces: electric force pulling on the small parti- es is clearly much larger than the gravitational forces exerted by the earth on e particles.

Next, small bits of charged plastic, suspended from threads, are tested near her charged bodies. You'll notice that bodies with unlike charges attract each her; with like charges, they repel.

Finally, two rods (one plastic, one glass) are charged up and brought near me charged pieces of plastic. The two rods have opposite effects on the plastic ts, showing that the rods have opposite types of charge.

Lesson 20 - Electrostatics, Cont'd.

Remember that when we say a body is charged, it is the same as saying it has a "net" or "excess" charge - that is, more of one type of charge than another.

Now, please ask the proctor for film loop 80-281, "Introduction to Electrostatics". After seeing that, listen to lecture 20A.

Outline to Lecture 20

$F_{\text{Electrical}} = \frac{KQ_1Q_2}{r^2}$ $F_{\text{Gravitational}} = \frac{KM_1M_2}{r^2}$

Like charges repel; unlike charges attract.

Since Q_1Q_2 is positive for like charges, we see that a force of repulsion is positive and a force of attraction is negative.

These electrical forces are the forces that hold matter together.

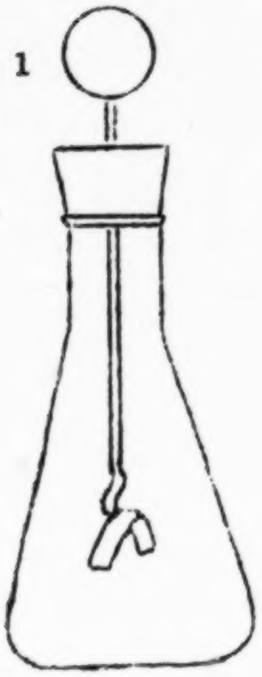
Conductor - substance in which charged particles can move about freely.

Insulator - substance in which charges are not readily able to move.

Under ordinary conditions, gases are insulators. However, ionized gases are conductors.

Some liquids, which would not be conductors if they were pure, are conductors, due to the presence of dissolved substances which break up into ions.

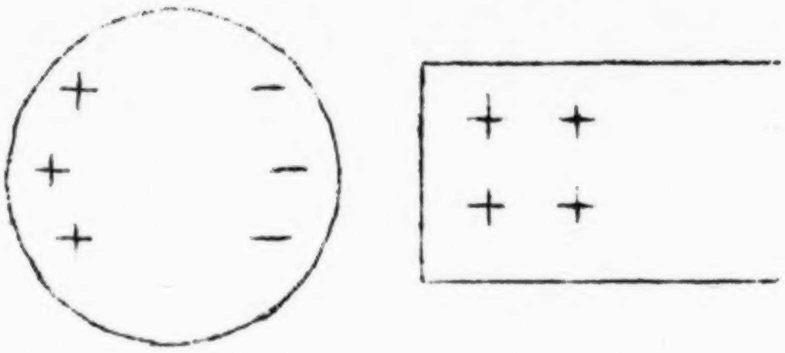
Figure 1



This is an electroscope which is used to show the presence of charge.

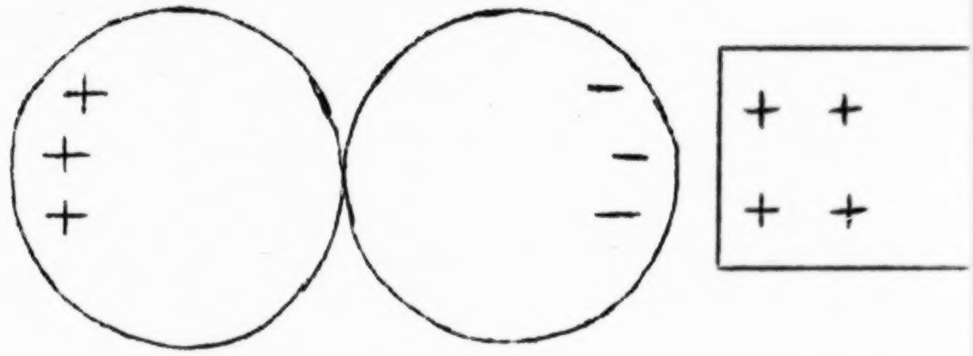
Grounding - the process of letting charge flow into the earth. Since the earth is very large, charge which flows into it does not change its total charge appreciably, and so the charge is effectively lost.

Figure 2



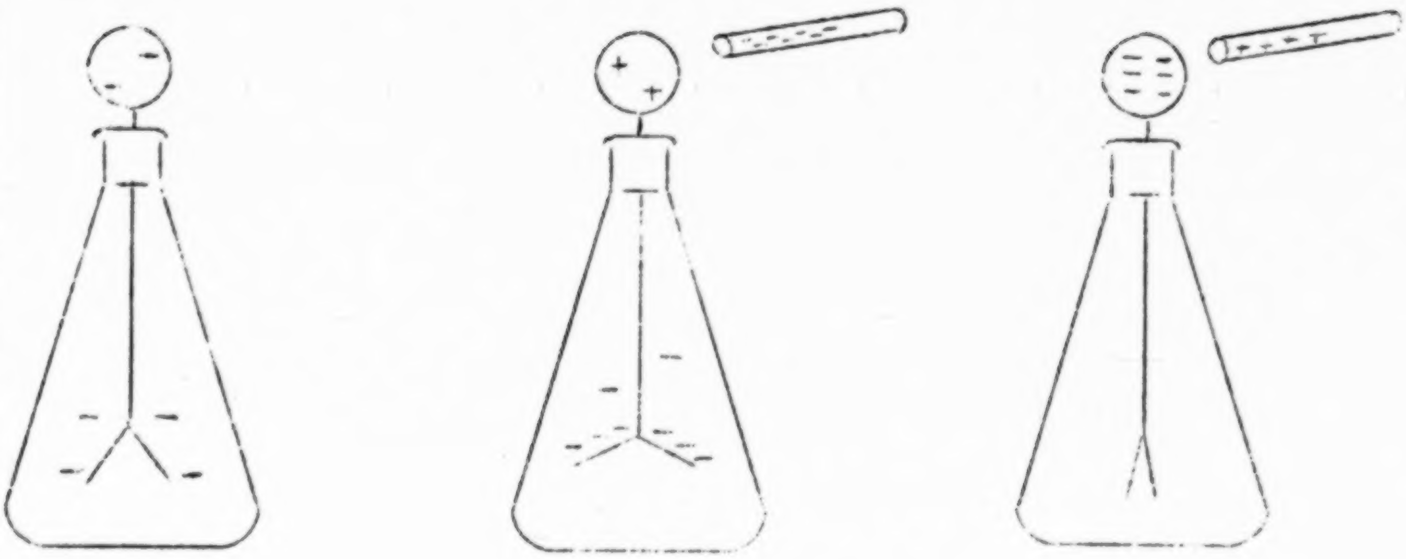
Bodies may be charged by contact with other charged bodies or by induction. lectrostatic induction means the separation of positive and negative charges on conductor induced by the presence of a charged body nearby, as shown above.

Figure 3



Objects charged by contact have the same type of charge as the objects with which they were contacted. Objects charged by electrostatic induction have the opposite charge.

Figure 4



ATTERIES

We've been charging objects by rubbing plastic with wool and transferring ome of the excess charges to the desired object, but there are other ways to do t. A convenient device to have around is a battery, which separates charge by hemical means instead of mechanical rubbing. Batteries can be used, for instance, o charge up a gold-leaf electroscope. Inside the battery, chemical action sepaates the positive and negative charges and causes the plus charges to move to the ositive terminal, despite the Coulomb force which is constantly attracting the ositive and negative charges to each other. If a conductor such as a wire, is conected between the battery terminals, negative charges will flow to the positive erminal. The chemical action inside the battery will continue to pump more egative charges back to the negative terminal, and positive charges to the posiive terminal.

This ends lecture 20. Please go back over any parts of it that you want to. hen you are ready, go to your terminal for a lecture quiz.

Outline of Lesson 21

All the charged bodies we have seen so far have much more than one unit of charge. This lesson will show what the fundamental unit of charge is and how it was found.

Figure 1a

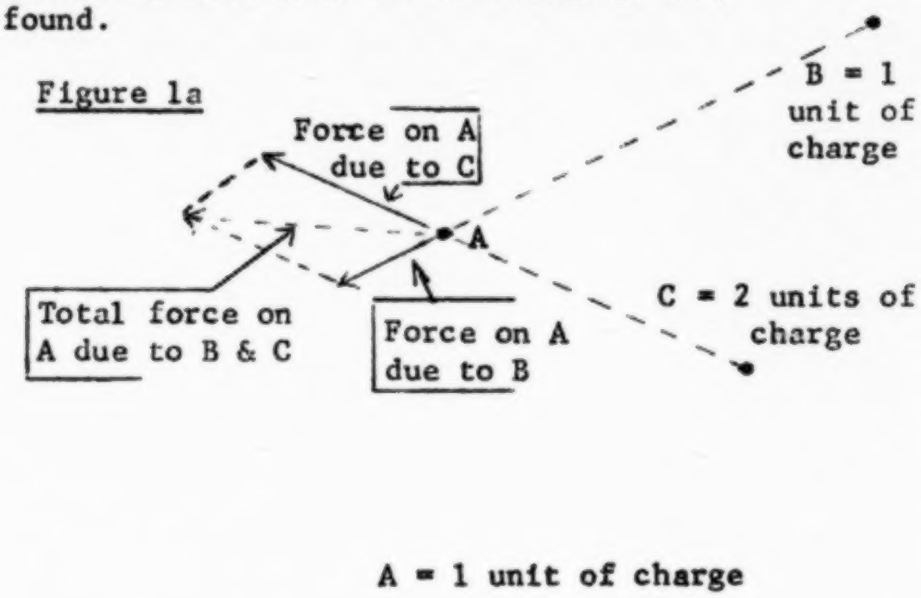

B = 1 unit of charge
Force on A due to C
A
Total force on A due to B & C
Force on A due to B
C = 2 units of charge
A = 1 unit of charge

Figure 1b

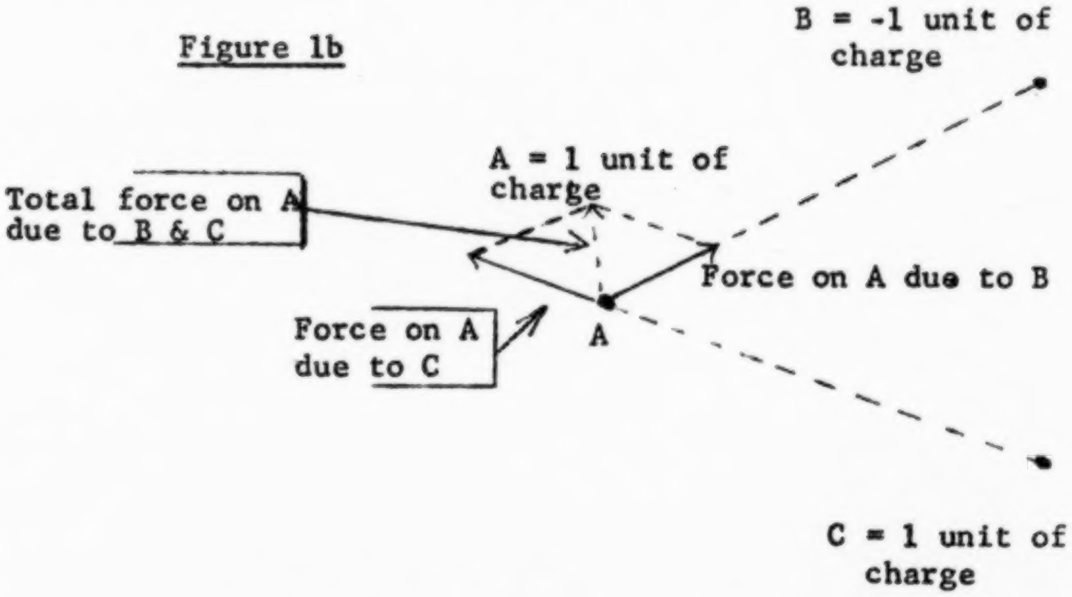
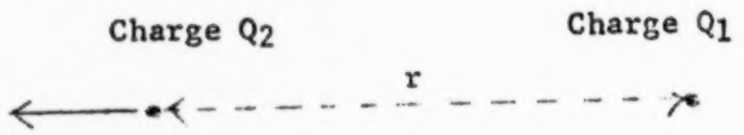
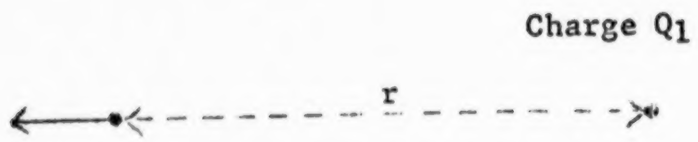

B = -1 unit of charge
A = 1 unit of charge
Total force on A due to B & C
Force on A due to B
Force on A due to C
A
C = 1 unit of charge

Figure 2


Charge Q_2
Charge Q_1
r

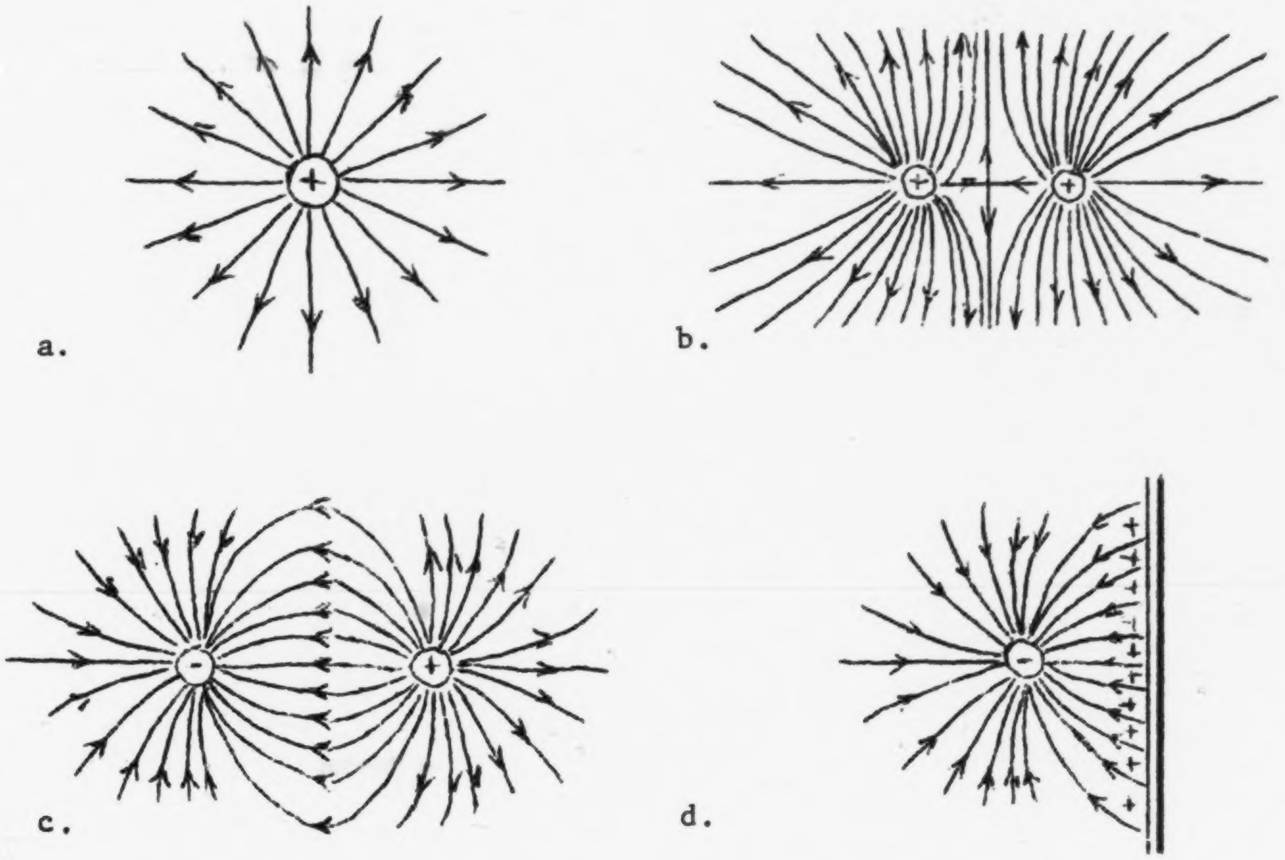
$$F = \frac{KQ_1Q_2}{r^2}$$



$$E = \frac{F}{Q_2} = \frac{KQ_1}{r^2}$$

E is the electric field due to Q_1 at the distance r from the charge Q_1. It exists regardless of whether charge Q_2 is present or not.

Figure 3 - Electric Fields



a. an isolated positive charge

b. two equal positive charges

c. two charges, equal in magnitude but opposite in sign

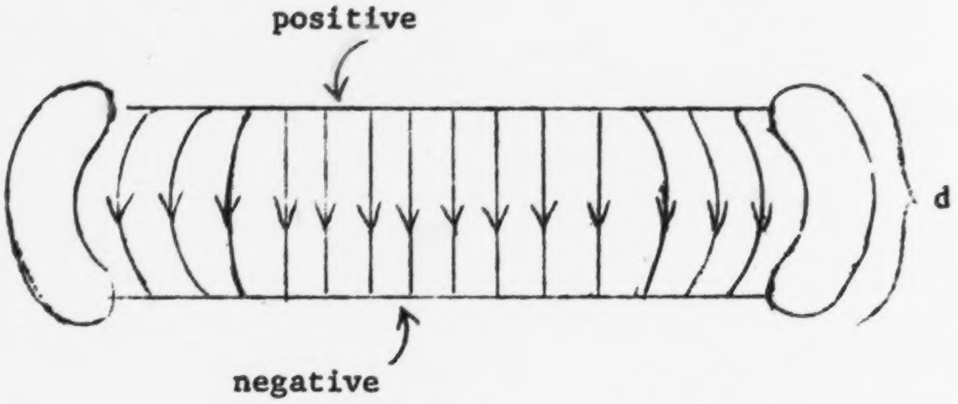
d. a single charge placed near a large conducting plane

Thomson showed that the charge to mass ratio of the individual electrons was always the same. (1897)

Millikan measured the charge of the individual electron and showed that all electrons have the same charge, as well as the same mass. (1909)

Outline of Lecture 22

Figure 1



A charged particle will have a potential energy due to its location in the electric field. This energy may be converted to kinetic energy, or vice versa, just as potential and kinetic energy may be interchanged in the gravitational field.

$W = Fd = 1/2\ mv_f^2$

where

W = work done by the electric field in moving a positive charged particle from the positive plate to the negative plate

F = force exerted by the field on the charge = qE

d = distance moved by the charge = distance between plates

m = mass of the charge

V_f= final velocity of the charged particle as it hits the negative plate

Important: both the kinetic and potential energy of the particle depend upon the particle's position at a given instant.

Note: Do not confuse "elementary charge" with "unit charge". The elementary charge has the magnitude of the charge of an electron. It is called elementary because no one has ever found a smaller charge than this. Unit charge, in contrast, is the amount of charge which counts as one in the particular system you are using. In Van Name, the system you are using is set up such that the elementary charge (i.e., the charge whose magnitude is the same as that of one electron) is 1.6×10^{-19} coulomb. On the other hand, the unit charge in this system is 1 coulomb.

If qEd is potential energy of a charge, $\frac{qEd}{q}$ = Ed is electrical potential the charge experiences.

Potential difference = the difference between the potential energy a particle of unit charge had when it started and the potential energy it had at the end of its path.

Note: Force and potential energy depend on the charge of the particle involved.

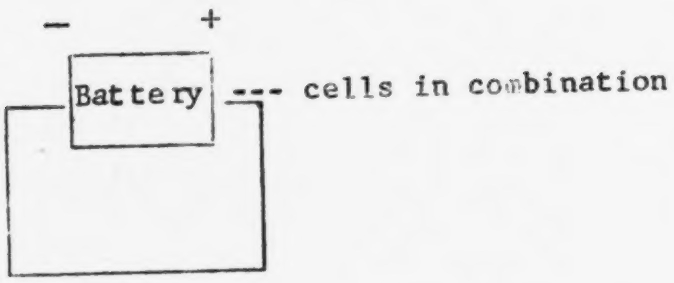
Electric field and electrical potential are both for unit charge. That is, they are both properties of the field, independent of the size of the particle involved.

Current = a flow of charge (has units of coulombs/sec = amperes)

Resistance = tendency of a material to resist current flow

Some energy is dissipated as heat in a resistor.

Figure 2



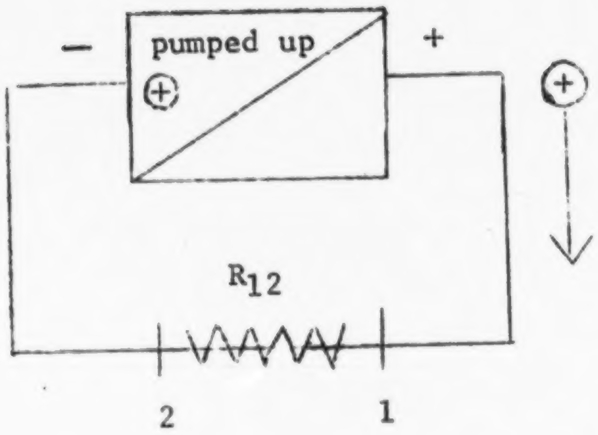
A battery (electrochemical cell) develops a constant amount of electrical energy per unit charge. This energy/unit charge is called emf (electromotive force).

A battery causes a potential jump (positive potential difference) while other parts of the circuit cause a potential drop.

$$\text{Power} = \text{Energy/time} = \frac{q \cdot \text{emf}}{\text{time}} = \frac{I\ t\ \text{emf}}{t} = (I\ \ \text{emf})$$

I = current

Figure 3



$V_{12} = IR_{12}$ (Ohm's Law for part of circuit)

emf = IR (Ohm's Law for whole circuit) where emf is that of battery.

R is total resistance of whole circuit.

To find power expended in heat production in the circuit:

$$\text{emf} = IR$$

To get power, multiply both sides by I

$$(I)\ (\text{emf}) = I^2R$$

This says that the power put forth by the battery is equal to the power dissipated due to the resistance. Since power is energy/time, this equation also says that energy is conserved in the circuit.

Useful things to keep in mind:

EMF is measured in volts.

Magnitude of volt: 1 volt = 1 joule/coulomb

1 elementary charge = 1.6×10^{-19} coulomb

Therefore: 1 volt = 1.6×10^{-19} joule/elementary charge.

There are 6.25×10^{18} elementary charges in one coulomb.

Current is measured in amperes and has units of amount of charge per unit time.

Magnitude of ampere: 1 amp. = 1 coulomb/sec.

Power is measured in watts and has units of work per time.

Definition of watt: 1 watt = 1 joule/sec.

Resistance is measured in ohms.

Definition of ohm: $1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ amp.}}$

Outline for Lecture 23

Figure 1a

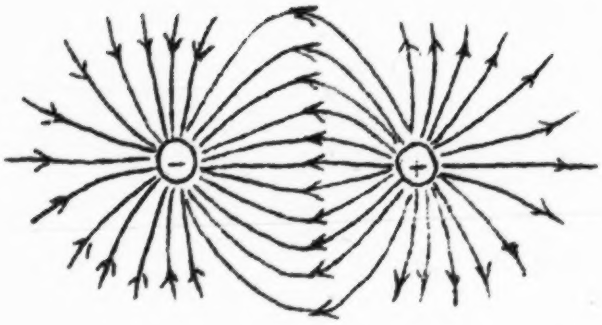
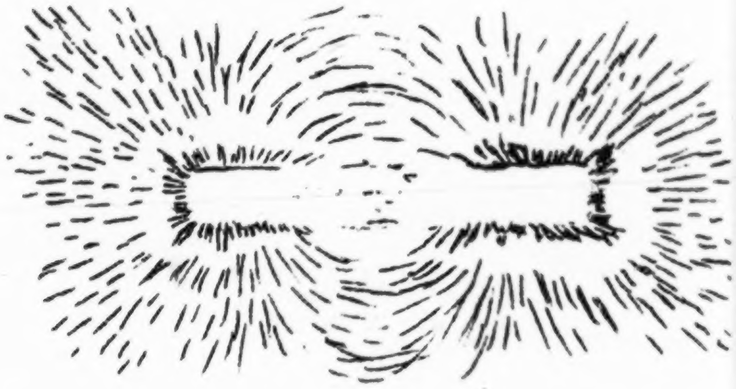


Figure 1b



Notice how similar the magnetic field lines are to the set of electric field lines above. However, in the magnetic field, the lines actually pass through the body of the magnet.

Magnetic lines form closed loops. Electrical lines originate at a source and terminate at some other charge or charges.

As with electrical charges, two similar magnetic poles repel each other and two opposite magnetic poles attract each other.

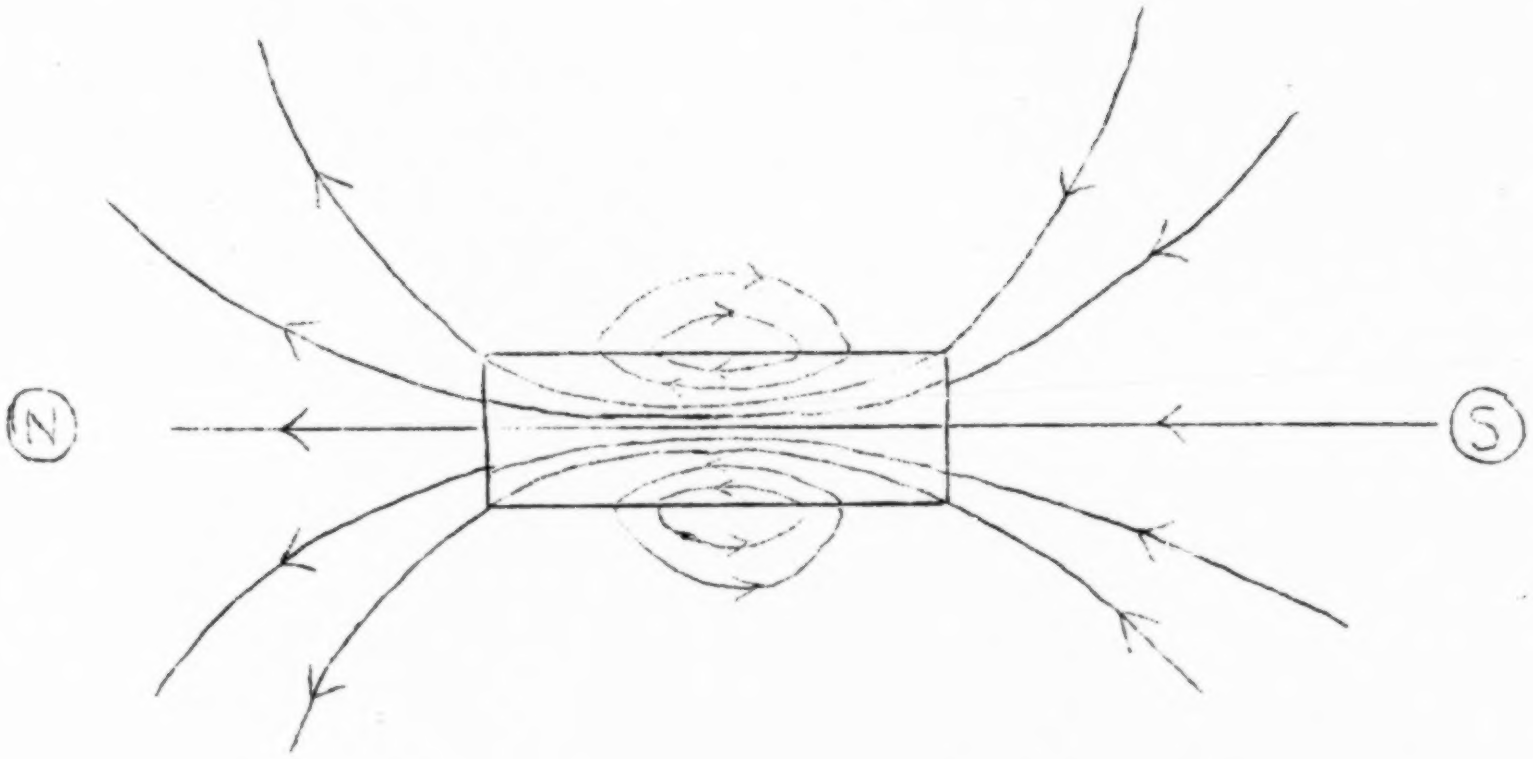


Figure 1c.

~~Magnet~~ Magnetic lines as drawn from iron filing patterns such as in 1b. Notice that the lines form closed loops. Some of the loops are too large to be completed on a page; the lines near the ends of the magnet which do not appear to form closed loops are actually parts of very large closed loops, too large to draw completely.

Postulate 1 - Moving charges produce magnetic fields.

Note: Moving charges are currents, so currents set up magnetic fields.

Right hand rule for the direction of a magnetic field due to a current (see Fig. 2a):

> Grasp wire with right hand, pointing thumb in direction of positive current. Your fingers are now curling around the wire in the direction of the magnetic field.

Comments on film loop FSU-33 Magnetic Field Near A Wire

As you would expect, there is a direct relationship between the magnitude and direction of the current in a straight conductor and the magnitude and direction of the magnetic field it produces. It is found that for this case, the magnetic field at a perpendicular distance d from the wire, carrying current I is given by:

$$B = 2\text{x}10 \quad I/d$$

with I in amperes and d in meters. B will be in webers/square meters.

A second demonstration film is similar to this first one except that it just looks more complicated. Here a bar magnet hangs between two large flat coils of wire. When a current is set up in the coils, the suspended magnet aligns itself with the magnetic field set up by the moving charges in the coils. When the current is reversed, the magnet assumes the opposite orientation.

Now view this demonstration in film loop FSU-35 Torque on a Magnet.

After viewing the film, continue with the audio lecture - part 23b.

Postulate 2 - Magnetic fields exert forces on moving charges.

Note: Moving charges are currents, so magnetic fields exert forces on the charges which make up currents.

Right hand rule for the direction of the force on a moving charge due to a magnetic field:

> Hold your right hand so that your thumb is pointing in the direction in which the charge is moving and your index finger points in the direction of the field at the location of the charge. The force acting is perpendicular to both your thumb and index finger and has the direction coming out of the palm of your hand.
>
> If the charge is moving in a direction perpendicular to the magnetic field, the magnitude of the force on the charge is $F = qvB$, where q = charge, v = velocity of charge, and B = magnetic field strength.

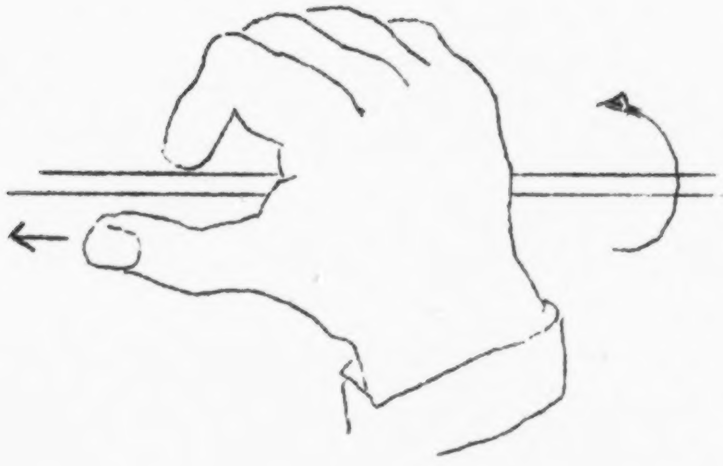


Figure 2a

Right hand rule for direction of a magnetic field due to a current.

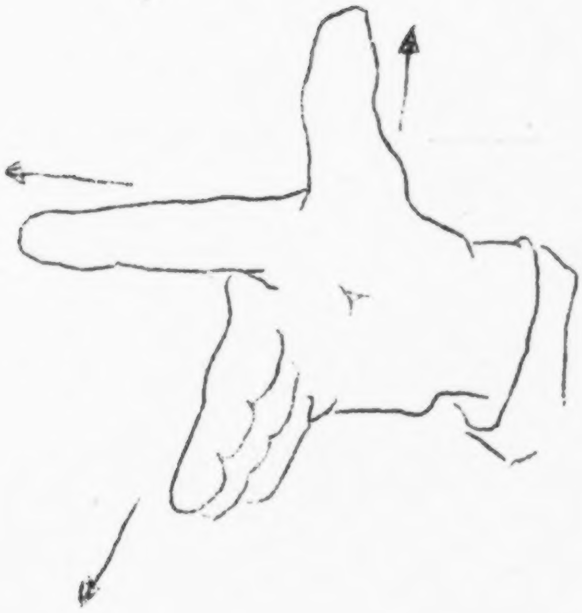


Figure 2b

Right hand rule for the direction of the force on a moving charge in a magnetic field.

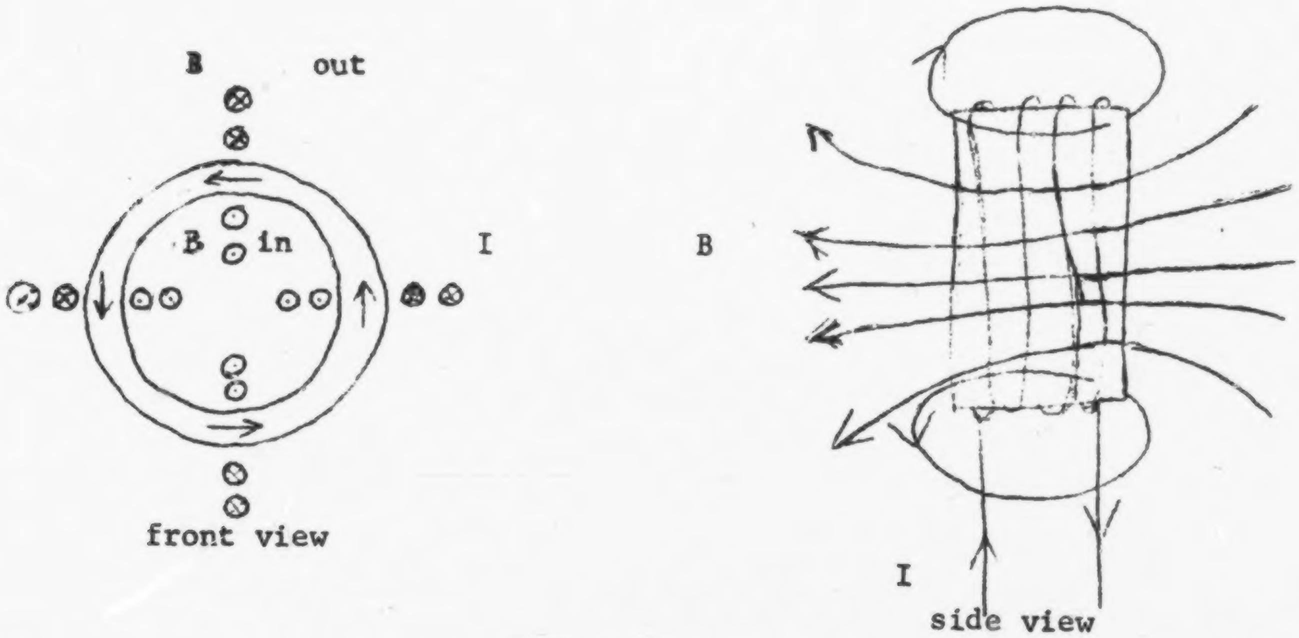

B
out
B
in
I
front view
B
I
side view

Figure 2c

The magnetic field of a current carrying coil.

The previous page was about the force of a magnetic field acting upon a moving charge.

But if a stationary charge is placed in a moving magnetic field, it sees the same thing as if it were moving and the field were standing still. So moving magnetic fields do exert forces on stationary charges. Again:

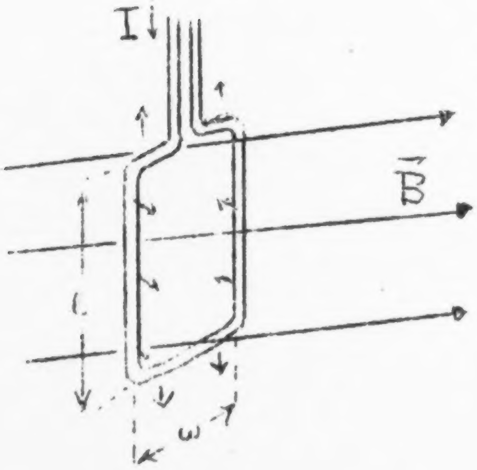
$$F = qvB$$

Since an atom consists of a nucleus surrounded by orbiting electrons, then these whirling electrons constitute a tiny current and so set up a small magnetic field.

But, in most substances, these little current loops take random positions and so their effects cancel each other.

Those substances in which some of the current loops can be given a uniform direction are magnetizeable.

Figure 2



Magnetic force can be used to turn a wheel.

When charges flow through the rectangular coil, the magnetic forces qvB on all moving charges tend to twist the coil since the v's are in opposite directions. Check the directions of the forces on the loop by using the right hand rule.

FILM NOTES

#33 MAGNETISM: FIELD NEAR WIRE

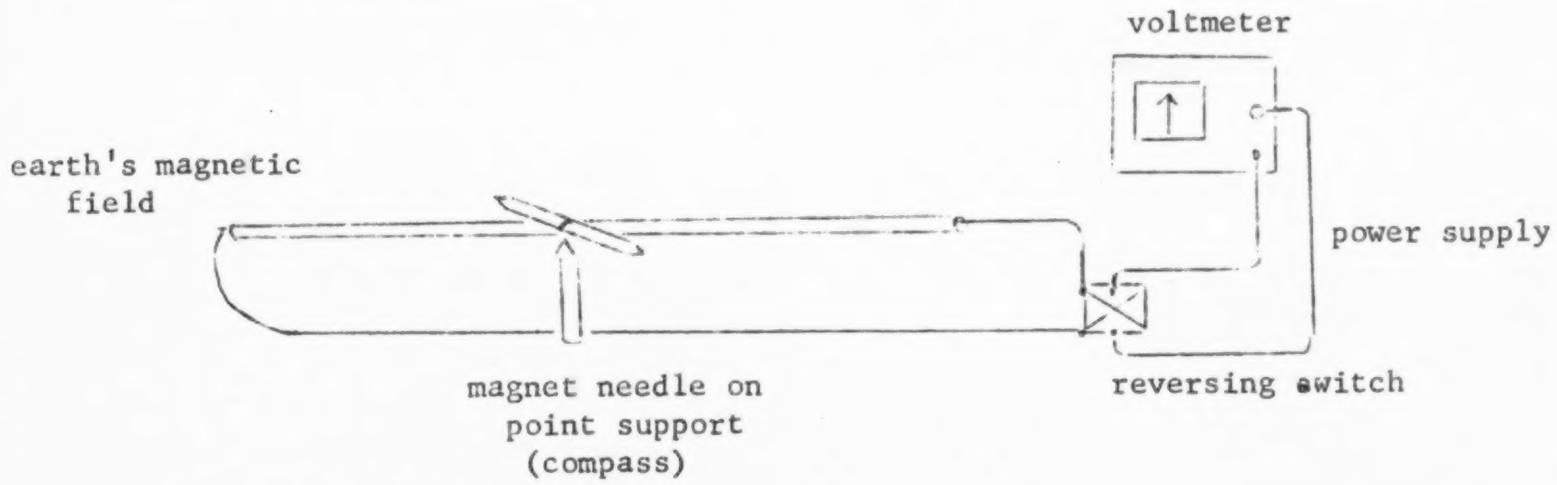
OBJECTIVE

To illustrate the direction of a magnetic field about a long wire.

BASIC CONCEPT

A wire carrying a current has a magnetic field about it.

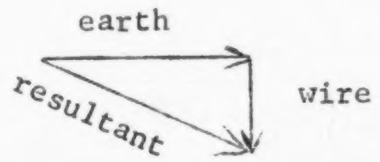
DEMONSTRATION APPARATUS


voltmeter
earth's magnetic field
power supply
magnet needle on point support (compass)
reversing switch

DEMONSTRATION PROCEDURE

1 With the current off, the compass lines up with the horizontal component of the earth's field. The wire has been lined up with the horizontal component of the earth's field.

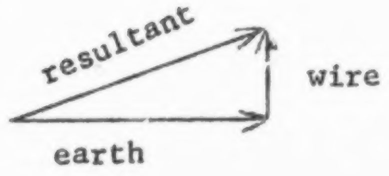
When current flows through the wire, the magnet rotates so as to line up with the direction of the resultant field of the earth and the wire.


earth
resultant
wire

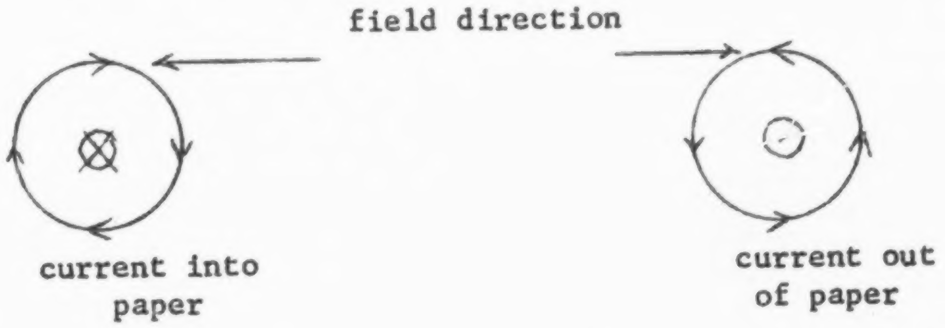
Thus the direction of the field of the wire is as indicated.

2 With the current reversed (by throwing the switch in the opposite direction) the magnet rotates to line up with the new resultant field.

In this case, the field of the wire has reversed to the opposite direction as indicated below.


resultant
wire
earth

3 The direction of the field of the wire is proposed to be circular about the wire in a direction as determined by the direction of the current.


field direction
current into paper
current out of paper

4 To illustrate the change of direction of the field above and below the wire, the magnet is moved above the wire.

The current is reversed and the magnet is moved above the wire.

In both cases, the above rule in 3 is substantiated.

CONCLUSIONS

In your own words, what have you learned about the magnetic field about a wire?

FILM NOTES

#34 MAGNETISM: FORCE ON A CURRENT

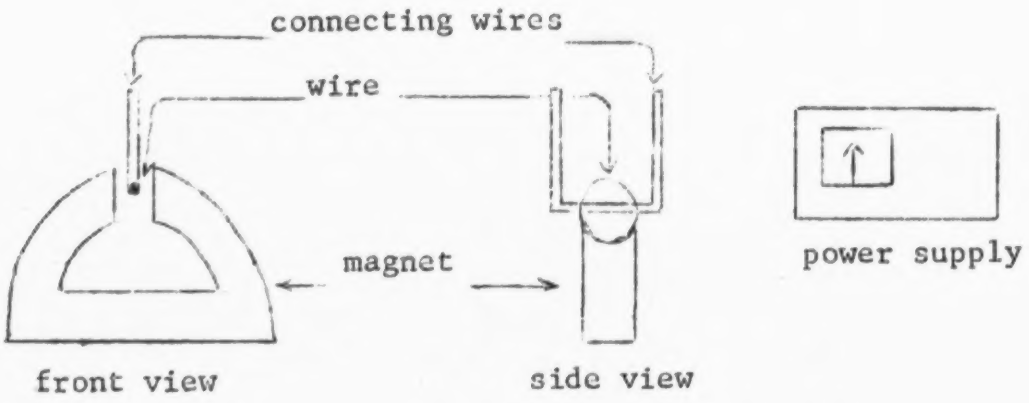
OBJECTIVE

To illustrate the force on a current-carrying wire in a magnetic field.

BASIC THEORY

A current-carrying wire in a magnetic field has a force exerted on it.

DEMONSTRATION APPARATUS



DEMONSTRATION PROCEDURE

1 A close-up view shows the wire and connections. With no current, the wire swings freely.

2 With current in the wire, coming towards the camera, the wire has a force exerted on it.

If the current is reversed, the direction of the force is reversed.

3 With a side view, the demonstrations are repeated.

CONCLUSIONS

What do you conclude about the magnetic force on a current-carrying wire?

FILM NOTES

#36 MAGNETISM: TORQUE ON A COIL

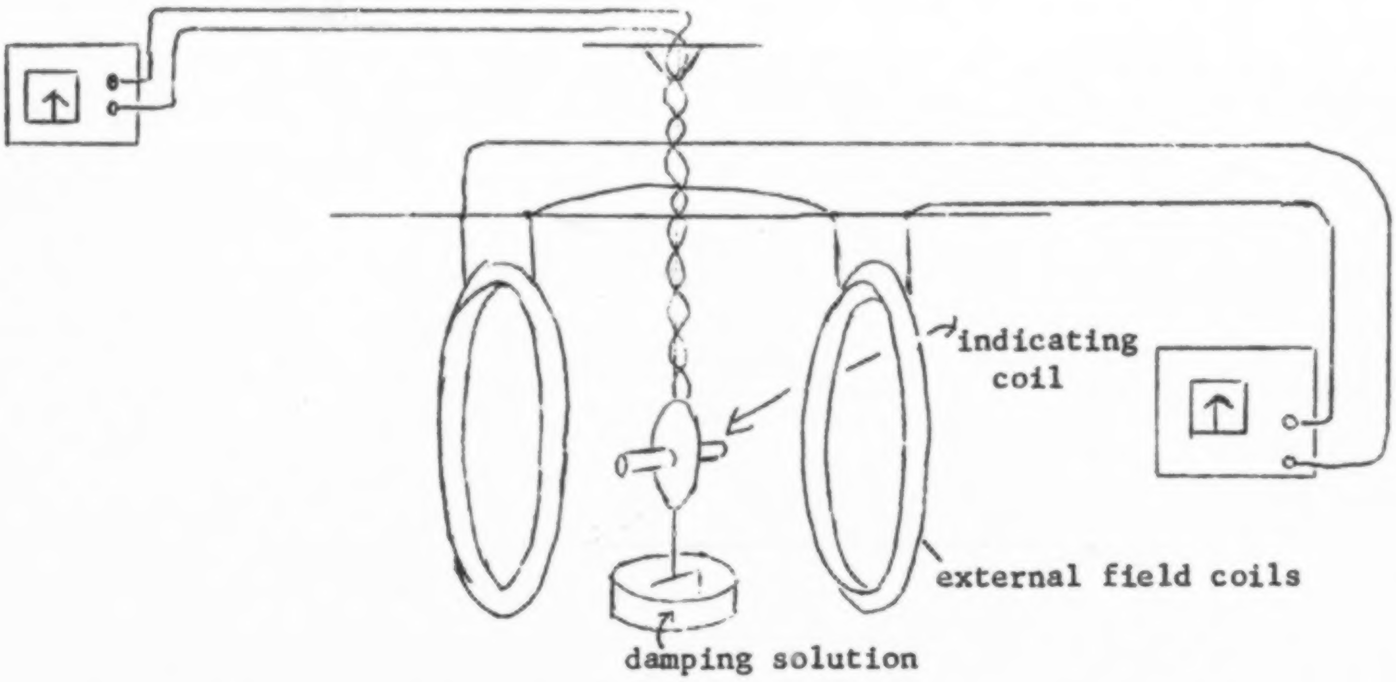
OBJECTIVE

To illustrate the torque on a current-carrying coil in a magnetic field.

BASIC THEORY

An external magnetic field will exert a torque (rotational force) on a current-carrying coil that will tend to line up the axis of the coil with the direction of the net external field.

DEMONSTRATION APPARATUS



DEMONSTRATION PROCEDURE

Note: The direction of the indicator coil magnetic field, along its axis and close to the coil, is given by the red pointer, the direction and magnitude being fixed throughout the demonstration.

The current to the external field coils are arranged so that their fields add together on the axis in the area between the two coils. The current direction can be reversed.

The supporting spring for the small coil tends to exert a restoring torque.

#36 MAGNETISM: TORQUE ON A COIL

1 The apparatus is shown in detail. With no current through the field coils, the small coil comes to rest with its axis perpendicular to the axis of the two coils.

2 With current through the field coils, the small coil lines up with the net external field which is predominately the field of the two field coils.

With the current through the field coils reversed, the indicator coil reverses its direction to line up with the new resultant field.

CONCLUSION

What do you conclude from this demonstration?

Supplement for Lecture 24:

Induction

This lecture uses seven film loops (not eight, as the taped lecture says). The seven loops are: FSU numbers 32, 11, 14, 20, 15, 10, 30, in that order.

Review:

(1) Magnetic fields exert forces on moving charges

$$F = q\ v\ B_{\perp}$$

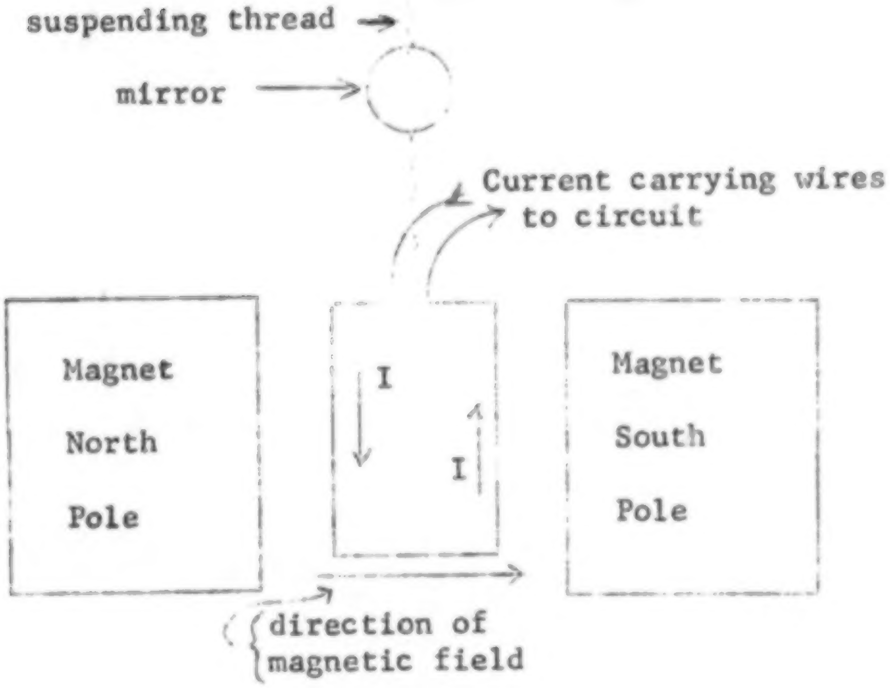
(2) Moving charges, i.e., currents produce magnetic fields.

For a straight, current-carrying wire

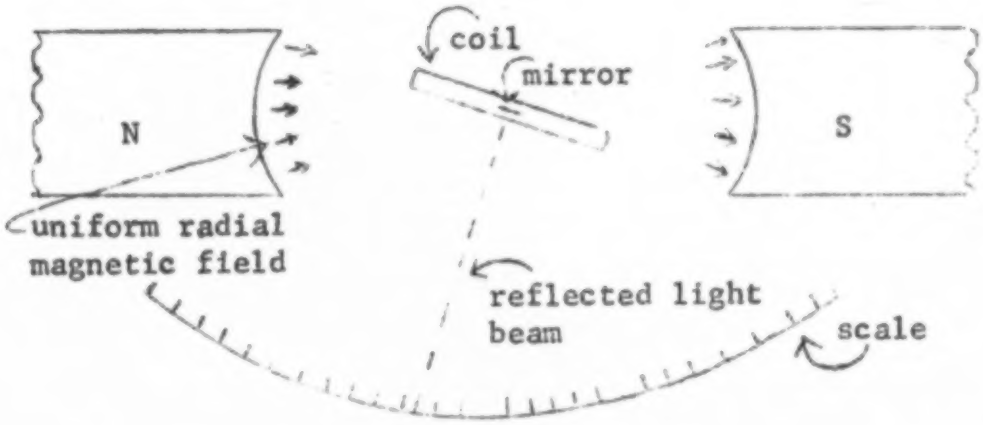
$$B = 2 \times 10^{-7} \frac{I}{d}$$

Lecture 24

Figure 1. The Galvanometer--a sensitive device for detecting currents


suspending thread
mirror
Current carrying wires to circuit
Magnet North Pole
I
I
Magnet South Pole
direction of magnetic field

Front View


coil
mirror
N
S
uniform radial magnetic field
reflected light beam
scale

View from Top

Demonstrations:

(1) Current is induced in a wire circuit as we move it through a magnetic field.

(2) Current is induced in a wire loop when a bar Magnet is pushed in and out.

In both demonstrations (1) and (2):

(a) Amount of current depends on speed of movement;

(b) Direction of current depends on direction of movement for a given magnetic field; and,

(c) If the direction of the magnetic field is reversed, the direction of induced current is reversed, also.

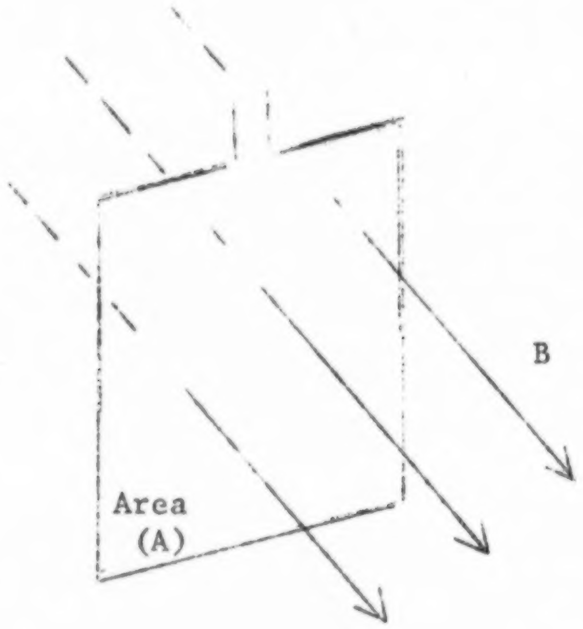
If ϕ = flux through A at a time t_1, and so on,

$$\Delta\phi = \phi_2 - \phi_1$$
$$\Delta t = t_2 - t_1$$

Equation 2 induced emf $= -\frac{\Delta\phi}{\Delta t}$

Figure 2.

Definition of magnetic flux ϕ through an area



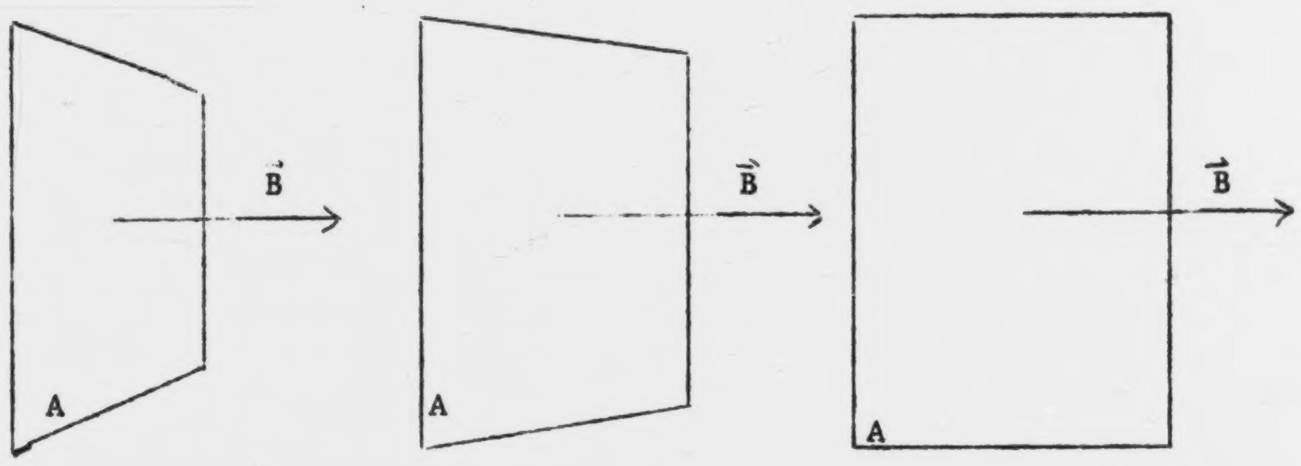
Flux $\phi = (A)\ (B_{\perp})$

ϕ in webers , A in $(\text{meter})^2$, $B_{\perp}$ in webers $/m^2$

Note: The shape of the area may be a circle, rectangle, or any shape whatever. Only the amount of area bounded by the wire is of importance in this formula.

$B_{\perp}$ = component of $\vec{B}$ perpendicular to the area A.

Figure 3. Component of $\vec{B}$ Perpendicular to Area A



$\vec{B}$ perpendicular to A	$\vec{B}$ neither exactly parallel nor perpendicular to A	$\vec{B}$ parallel to $\vec{A}$
$B_\perp = B$	$B_\perp$ = a fraction of B	$B_\perp = 0$
$\phi = (A)(B)$	$\phi = (A)(B)(\text{fraction})$	$\phi = (A)(0) = 0$

Film Loop FSU-15

Induced EMF: 2 coils

See Figure 4a. Demonstrations using two wire coils. Coil I is connected to a battery and a switch; it is the field-producing coil. Coil II is connected to a galvanometer; so any induced emf in Coil II may be detected by current flowing through the galvanometer.

(3) Switch opened and closed, turning current in Coil I on and off; thus changing flux through Coil II. Current observed in Coil 11.

(4) See Figure 4b. With steady current in Coil I, move Coil II away. Amount of flux through Coil II decreases, and induced current is observed in Coil II. When Coil II is moved back, induced current flows in opposite direction. No induced current when both coils are still.

(5) See Figure 4c. Swing Coil II sideways to a region of different magnetic field strength. Change in flux through II causes induced current in II.

(6) See Figure 4d. Turn coil II to a position perpendicular to area of Coil I. Change in flux again results in induced current in II.

Note: In all the above demonstrations; the induced current flows in Coil II only while the flux through II is changing, either due to relative motion of two coils, or to switching the field-producing current in Coil I on and off.

Demonstration 7. Two coils are moved in same direction with the same speed; no flux change through II, so no induced current. There is flux through the coil, but it is not changing.

Equation 3.

$$\text{Induced EMF} = -\frac{\Delta\phi}{\Delta t} = \frac{-\Delta(A\,B_{\perp})}{\Delta t}$$

Transformer effect.

Induced EMF proportional to the number of turns of wire in the loop.

LENZ's Law

Induced current is in such a direction as to oppose the change being made. If this were not the case, the conservation of energy principle would be violated.

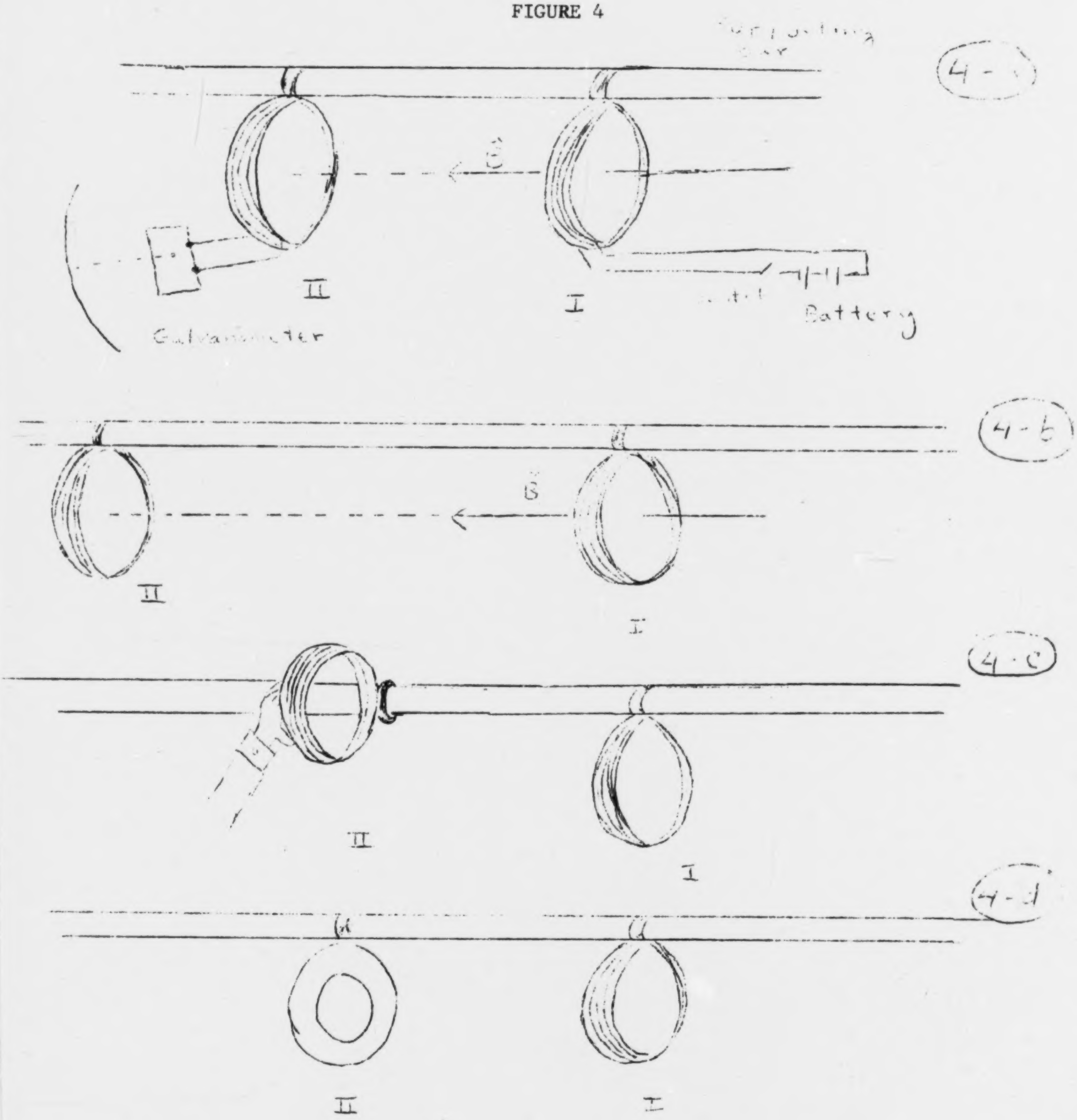
Examples:

(1) The "eddy-current" damping (or braking) of a pendulum

(2) The jumping rings.

Magnetism is really another manifestation of electricity. We are now in a position to answer the question, "In light, what is the medium that vibrates?" We will do so in lesson 25. Now view film loop FSU-30, then go to your terminal for a lecture quiz.

FIGURE 4


Supporting bar
4-a
B
II
I
Galvanometer
switch
Battery
4-b
B
II
I
4-c
II
I
4-d
II
I

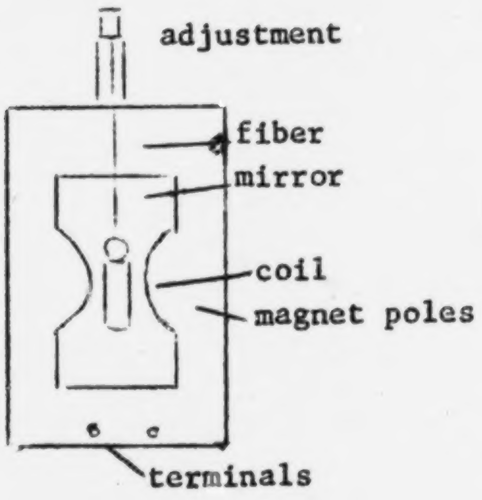
FILM NOTES

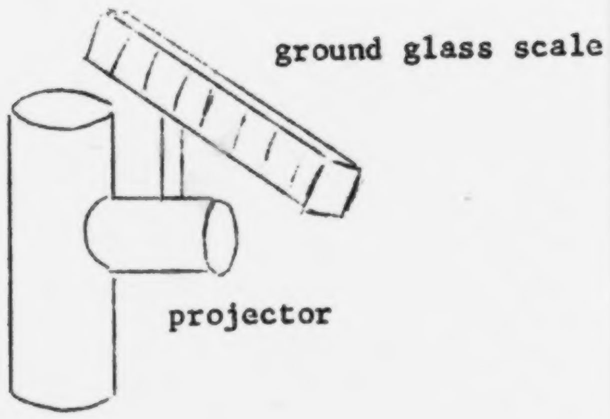
#32 THE GALVANOMETER

OBJECTIVE

To show the parts of a sensitive galvanometer

DEMONSTRATION APPARATUS


adjustment
fiber
mirror
coil
magnet poles
terminals


ground glass scale
projector

DEMONSTRATION PROCEDURE

Note: This type of galvanometer will be used in several films.

1 A general view is shown of the projector, scale and the galvanometer.

2 A close-up of the galvanometer shows in detail the mirror, coil, and pole pieces.

3 The response of the galvanometer is shown on the ground-glass scale.

The indicator is the focused image of the object on the projector - after having been reflected off the mirror.

A current through the galvanometer causes a rotation of the coil which is accompanied by the mirror rotation. The scale reading is indicative of the current.

FILM NOTES

#11 INDUCED EMF: WIRE MOVING THROUGH A MAGNETIC FIELD

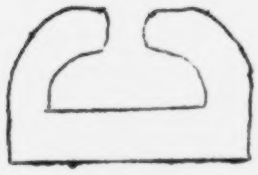
OBJECTIVE

To illustrate that moving a wire through a magnetic field generates an emf (and thus a current in a closed circuit).

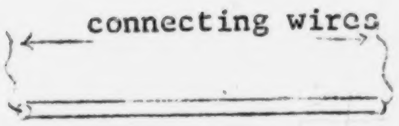
BASIC THEORY

Faraday's Law - An emf (and therefore a current) will be generated in a closed circuit by a changing magnetic field.

DEMONSTRATION APPARATUS



magnet



straight wire

galvonometer

DEMONSTRATION PROCEDURE

1 The wire is moved up through the magnetic field of the magnet and the galvanometer deflects - indicating a current was flowing through the wire.

The wire is moved down and the galvanometer now deflects in the opposite direction.

2 The motions are repeated.

Note that when the wire is at rest in the middle of the magnetic field, no emf is present. This is so according to Faraday's Law, isn't it?

CONCLUSIONS

What is the basic fact that you learned?

FILM NOTES

#14 INDUCED EMF: MOVING MAGNET IN COIL

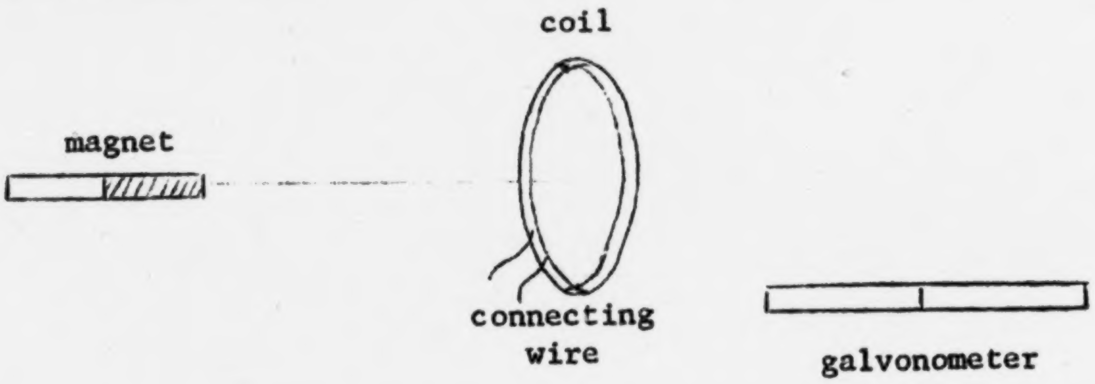
OBJECTIVE

To illustrate the principle of electromagnetic induction.

BASIC THEORY

Faraday's Law: An emf (a current) will be generated in a closed circuit by a changing magnetic field.

DEMONSTRATION APPARATUS



DEMONSTRATION PROCEDURE

1 Apparatus is shown.

2 The magnet is moved in along the axis of the coil and the galvonometer deflection is noted.

When the magnet is pulled out, the current is induced in the opposite direction.

The magnet is turned around. Now on thrusting the magnet in (or out) the induced currents are in the opposite direction from before.

The effect of a slow change of flux is illustrated.

3 A meter stick is placed on the axis of the coil. The magnitude of the magnetic flux change for different positions along the axis is illustrated.

Note that when there is no relative motion between the magnet and the coil, no emf is present. This follows from Faraday's Law - doesn't it?

CONCLUSIONS

What observations can you note from this demonstration?

FILM NOTES

#20 INDUCED EMF: H.F. RICHARDS EXPERIMENT

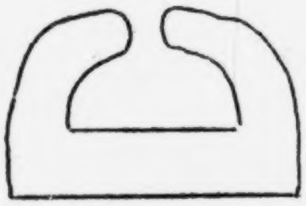
OBJECTIVE

To show a simple demonstration device for induced emf.

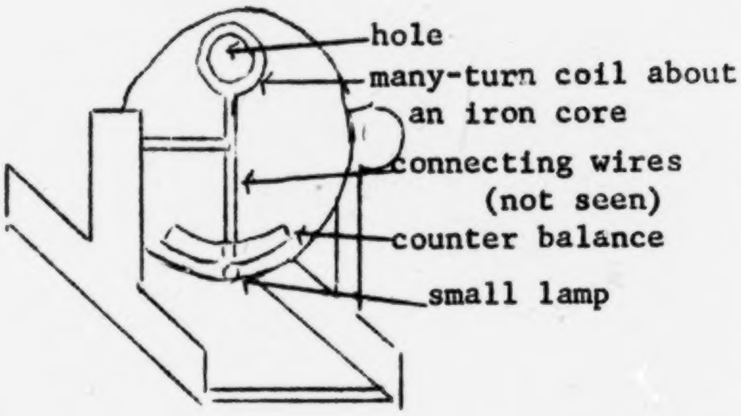
BASIC THEORY

Faraday's Law - A emf (and therefore a current) will be generated in a closed circuit by a changing magnetic field.

DEMONSTRATION APPARATUS



magnet


hole
many-turn coil about an iron core
connecting wires (not seen)
counter balance
small lamp

DEMONSTRATION PROCEDURE

1 The magnet is placed between the wheel and the wheel set into rotation.

The lamp glows indicating that a current has been generated. Due to the motion, the glow is smeared out.

The changing flux in the coil is accompanied by an induced current.

2 The wheel is shown in detail.

3 The wheel is rotated again.

CONCLUSIONS

In your own words, how does this experiment illustrate the law of induced emf?

FILM NOTES

#15 INDUCED EMF: TWO(2) COILS

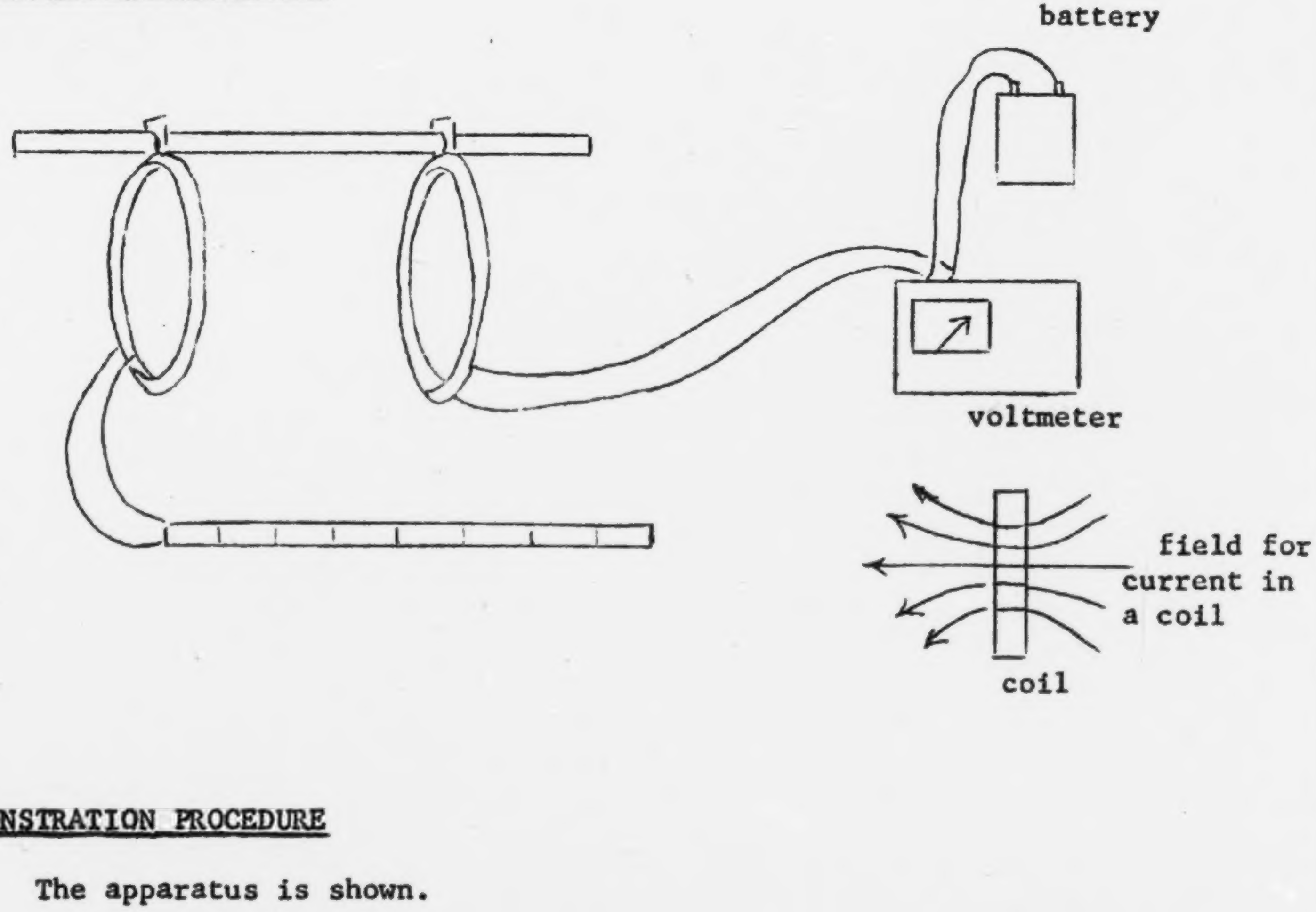
OBJECTIVE

To illustrate the principle of electromagnetic induction.

BASIC THEORY

Faraday's Law: An emf (and a current) will be generated in a closed circuit by a changing magnetic field.

DEMONSTRATION APPARATUS



DEMONSTRATION PROCEDURE

1 The apparatus is shown.

2 With the coils close together, the switch is closed, sending current through one coil. The galvanometer, connected in series with the other coil, is deflected indicating a current through the second coil.

The switch is opened and the galvanometer deflects in the opposite direction.

FILM NOTES

#15 INDUCED EMF: TWO(2) COILS - Page 2

The direction of the current is changed and the deflections noted on "make and break."

3 Next, it is noted that on closing the switch, there is a deflection which returns to zero, indicating that the emf is induced only while the flux changes.

With current in one coil, the other one is moved away from and back towards the current-carrying coil. The deflections are in opposite directions.

Note that moving one coil away gives the same effect as opening the switch; moving together the same as closing the switch.

4 One coil is backed up and rotated about a vertical axis and the deflection is noted.

5 If the two coils are moved together, no deflection is observed, indicating that there wasn't any flux change.

CONCLUSION

What have you learned from these demonstrations?

FILM NOTES

#10 EDDY CURRENT DAMPING

OBJECTIVE

To illustrate that eddy currents produce a damping effect on the motion of a conductor passing through a magnetic field.

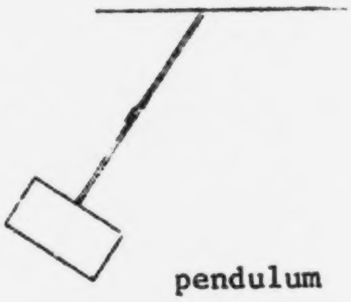
BASIC THEORY

Faraday's Law - An emf (and therefore a current) will be generated in a closed circuit by a changing magnetic field.

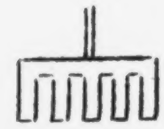
Lenz's Law - When the magnetic flux linking a closed circuit is changing, the flux set up by the induced currents is such as to oppose the changing flux.

DEMONSTRATION APPARATUS

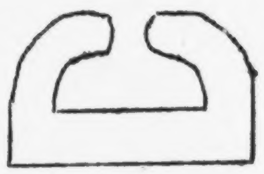
A simple pendulum having a rectangular metal plate and also a notched plate for a bob.



pendulum



notched pendulum



magnet

DEMONSTRATION PROCEDURE

1 The magnet and the pendulum are shown separately. It is demonstrated that the pendulum swings freely - with little reduction in the amplitude each swing.

2 The magnet is then positioned so that the pendulum "bob" swings between the pole pieces of the magnet.
The pendulum motion is now shown to be quite damped; i.e. it only makes about two swings before coming to rest!

This damping occurs because eddy currents are set up in the metal plate - according to the laws of Faraday and Lenz. The area in which these circulating currents are present is approximately that area directly between the magnet pole pieces.

3 The pendulum "bob" is replaced by the notched bob.
Now the pendulum motion is not damped as in the previous case.

In this case, the eddy currents are much more restricted in their circulating paths and considerably reduced in magnitude.

4 The damping effect on the solid plate is again demonstrated.

5 The "undamped" effect on the notched plate is demonstrated again.

CONCLUSIONS

What basic ideas did you learn?

FILM NOTES

#30 INDUCED EMF: LENZ'S LAW AND THE JUMPING RINGS

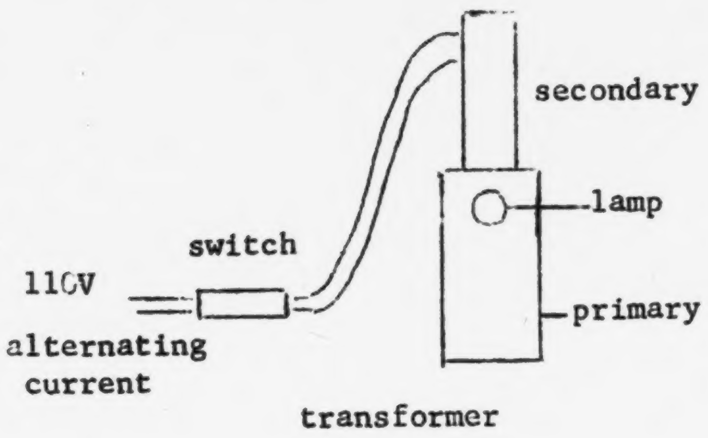
OBJECTIVE

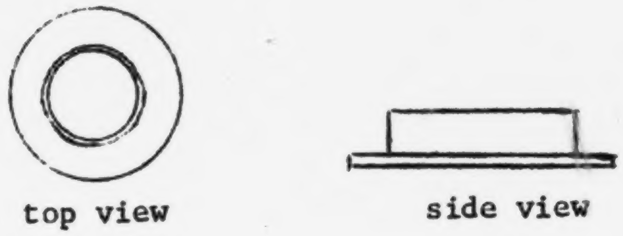
To illustrate induced emf and Lenz's Law.

BASIC THEORY

Lenz's Law - The induced currents are in a direction such as to oppose the change in flux.

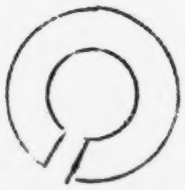
DEMONSTRATION APPARATUS

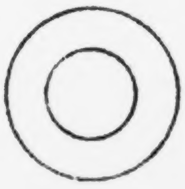


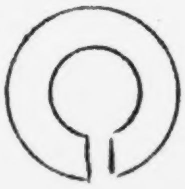

top view

side view

Ring #1


Ring #2


Ring #3


Ring #4

DEMONSTRATION PROCEDURE

Note: (1) When the current is on in the primary, the lamp glows.
(2) When the current is on, a fluctuating (60 cycles/sec) magnetic field is induced in the secondary.

1 Ring #1 (solid) is placed on the base of the secondary and the switch closed. The ring jumps clean off the top of the secondary!

This occurs because the changing magnetic field inside the ring induces eddy currents (Faraday's Law) and which are in a direction which opposes the changing field (Lenz's Law). The opposing magnetic fields, that of the secondary and that of the primary, result in opposing forces and the ring does the moving.

It is also shown that the magnetic force, after the switch has been on, is sufficient to support the weight of the ring at an intermediate position along the secondary.

2 Ring #2 (split) is placed on the base of the secondary and the switch closed.
The split ring does not move! This is because (?) ______________

____

3 Ring #3 (solid and flat) does jump.
It is also shown that the induced currents heat the metal ring so that it is very hot to the touch.

4 Ring #4 (flat and split) does not jump - because (?) ______________

____

CONCLUSIONS

In your own words, what has this demonstration shown?

Outline to Lecture 25

Important results from last two lessons:

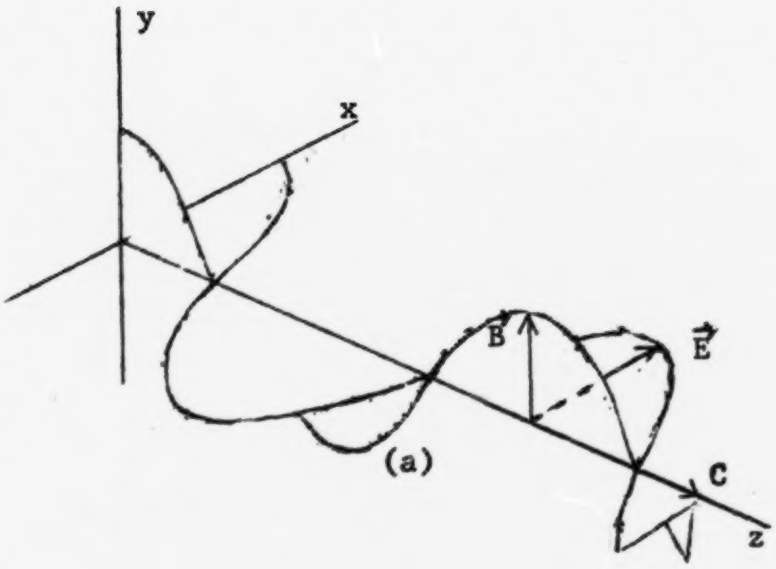
(1) Moving charges produce magnetic fields

(2) Magnetic fields exert forces on moving electric charges

(3) Changing magnetic fields set up electric fields

Assertion: Light waves consist of fluctuating electric and magnetic fields. These fields are perpendicular to each other and are both perpendicular to the direction of propagation.

Figure 1.



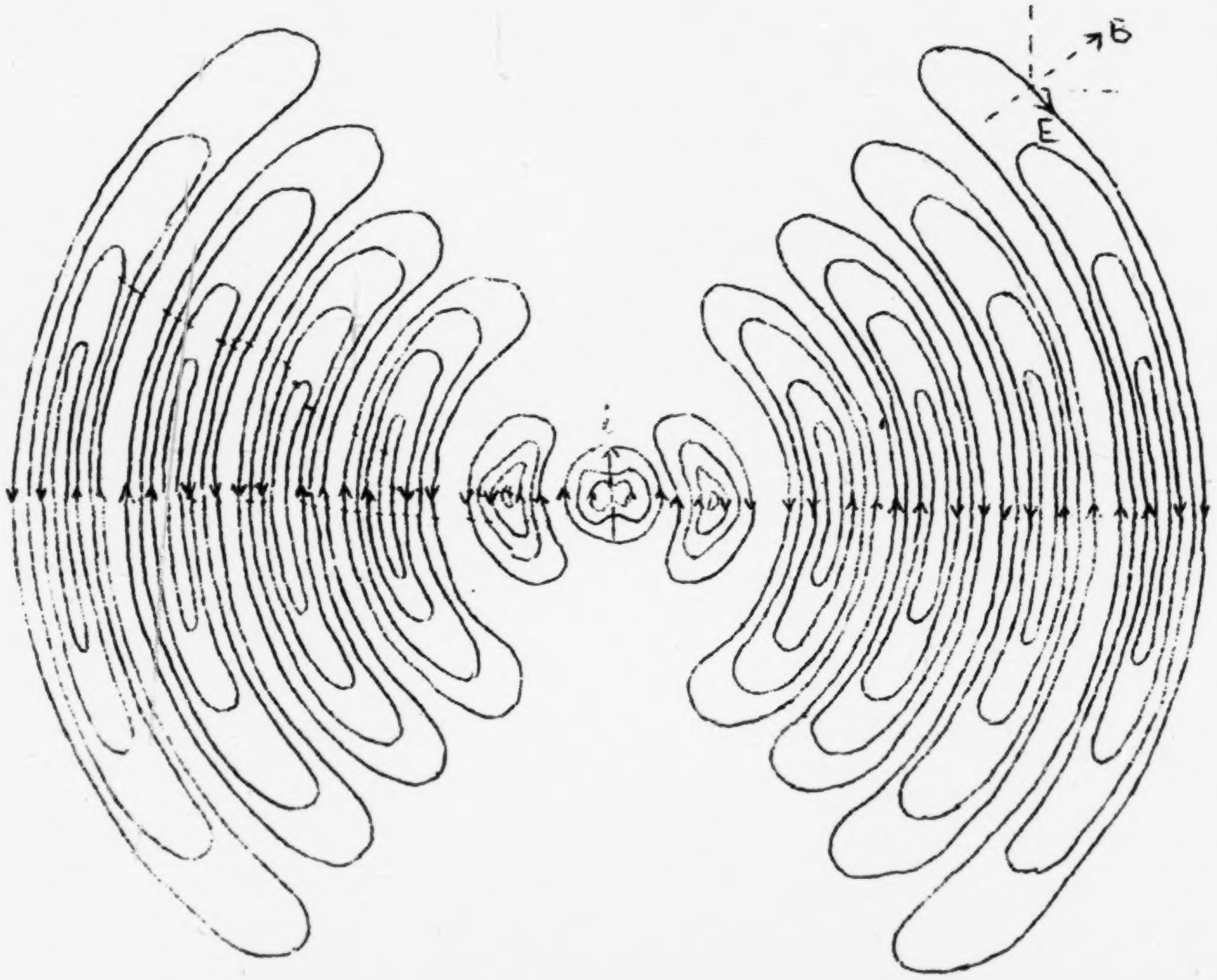


Figure 2

Maxwell did calculations based on the assumption of the previous page and was able to show that this combination of fluctuating electric and magnetic fields would propagate at exactly the speed of light! Further, other phenomena, like radio waves, microwaves, infrared rays, ultra-violet rays, X-rays and gamma rays, also consist of fluctuating electric and magnetic fields, and also propagate with exactly the speed of light!! All these phenomena can be classified as electromagnetic waves. They differ in frequency of vibration and wavelength, but are all combinations of fluctuating electric and magnetic fields, and they all propagate with the same velocity in a vacuum.

Summary of the Experiment on Measuring the Mass of the Electron

Electrons are accelerated through a potential difference V in a cathode ray tube. This tube is mounted midway between two parallel bundles of wires carrying currents in opposite directions; which establish a fairly uniform magnetic field B perpendicular to the electron beam. This beam is deflected in a circular arc causing the spot on the tube face to move. Professor Rogers measures the radius of this arc.

The kinetic energy transferred to each electron is calculated by:

(1) $qV = 1/2\, mv^2$

v in m/sec
V in volts
q in coulombs
m in kg.

The magnetic field B at the midpoint between the wires can be calculated from:

(2) $B = 2 \times 2\times10^{-7} \frac{I}{d}$

I in amps.
B in weber/m^2
d in meters

where $2 \times 10^{-7} \frac{I}{d}$ is B due to each wire,

I = current in wire

d = distance from wire.

We know that the force which bends the electron is the force of deflection due to the magnetic field which must equal the centripetal force.

(3) $qvB = \frac{mv^2}{r}$, or

(4) $m = \frac{qvBr}{v^2} = \frac{qBr}{v}$

We know that q is the charge of one electron. Dr. Rogers measured r for the experiment. We can find values for v from (1) and B from (2). When we plug all these numbers in, we find that the mass of an electron is 9.18×10^{-28} grams.

$= 9.18 \times 10^{-31}$ Kg.

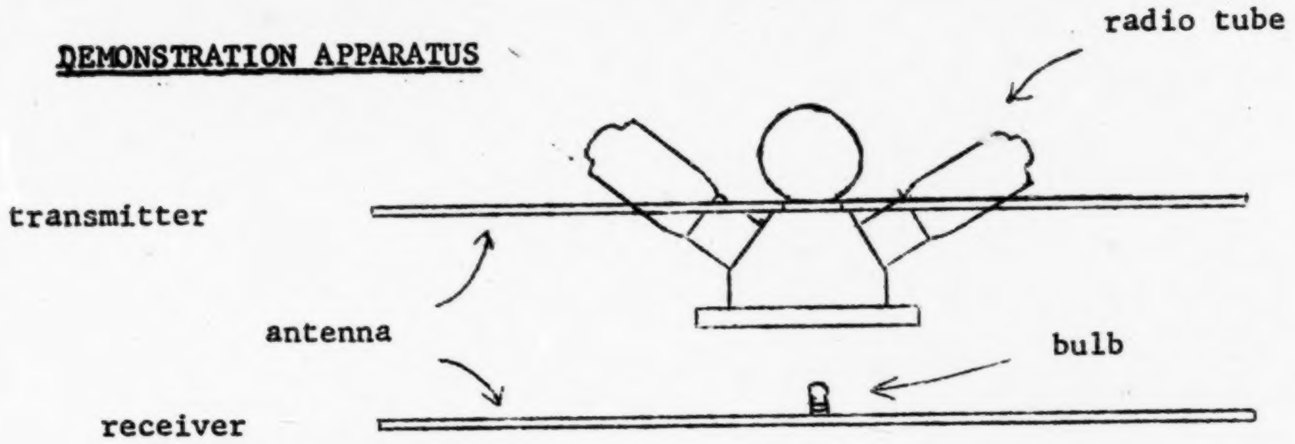
FILM NOTES

#13 INDUCED EMF: MICROWAVE RADIATION

OBJECTIVE

To illustrate that electromagnetic radiation travels through space and the nature of the transmitted radiation.

DEMONSTRATION APPARATUS



DEMONSTRATION PROCEDURE

1 The transmitter is shown.

2 The receiver is placed in front of the transmitter and the bulb glows - showing that a current is present in the rod, an alternating current in this experiment.

The current is generated by the progression of the radiation as it passes the receiver.

3 The effect of receiver orientation and distance is demonstrated.

Here we see that the transmitted radiation (1) is emitted in a horizontal plane*and (2) has less intensity at greater distances from the source.

4 From the side, the orientation and distance effect is repeated.

5 A receiver with five equally spaced bulbs shows the difference in the current values along the rod.

*Remember that this observation is based on the transmitter being in a horizontal plane.

6 A fluorescent tube is placed in contact with the transmitter and the tube lights up. The variation in the intensity along the tube is changed by placing the hand about the tube.

Here, the radiation excites the gas in the tube and causes it to discharge.

When the hand is placed on the tube, part of the radiation travels to the body, thereby lessening the glow in the tube above the hand.

CONCLUSIONS

What have you learned from this demonstration?

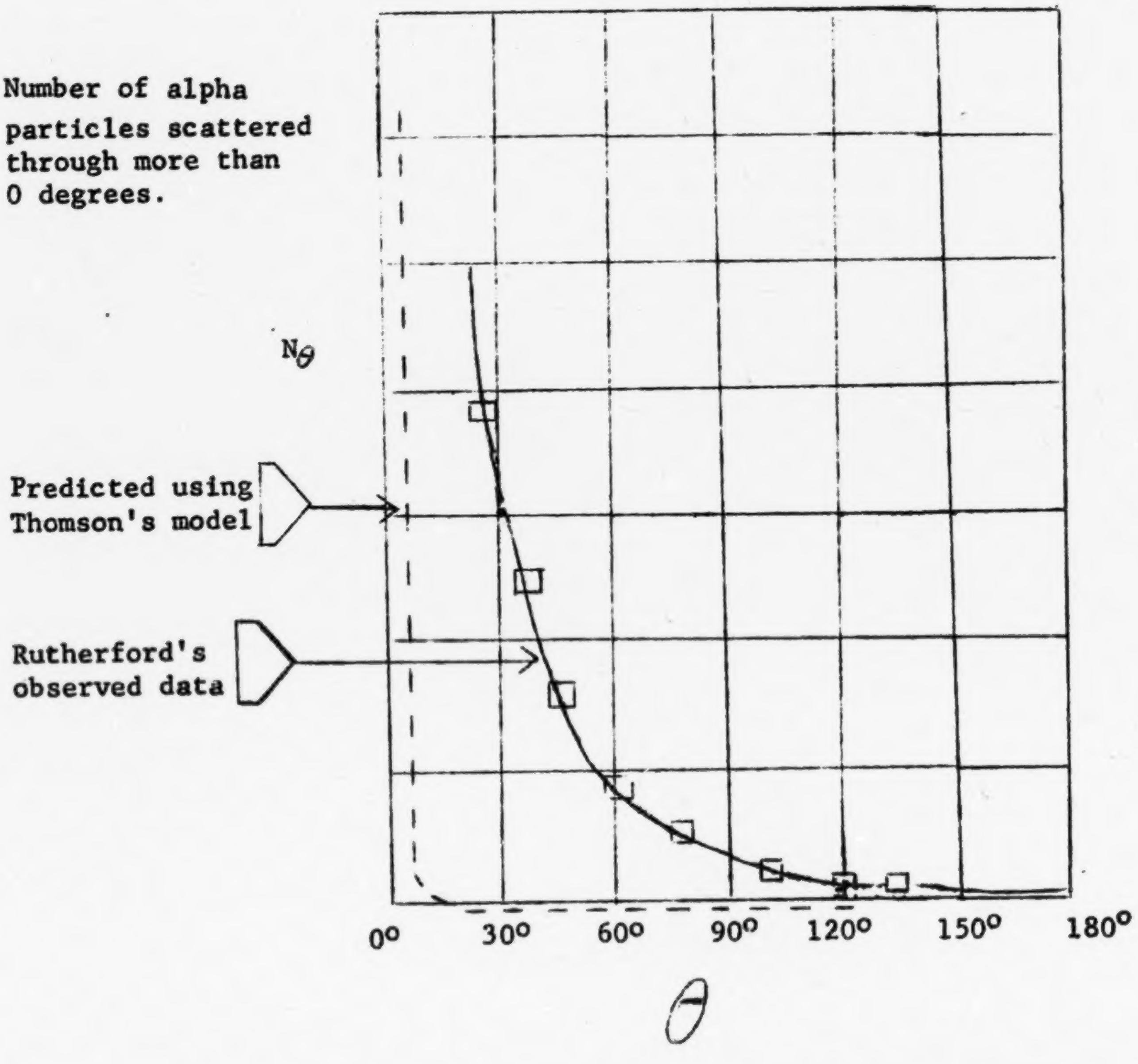
Outline of Lecture 26

Thomson's "plum pudding" model of atom.

Alpha particle: About four times more massive than a hydrogen atom and about 8000 times more massive than an electron. Positively charged with magnitude two times that of an electron.

Rutherford's scattering experiment

Figure 1.



Consideration of conservation of energy and momentum in an elastic collision between two bodies shows that an object will only bounce directly backwards from its origional direction when it strikes a more massive object in a head-on collision. Here we see that a very few, but nonetheless some, alpha particles bounced straight back. So some parts of the gold atoms were heavier than the alpha particle, in disagreement with the "plum pudding" model.

Rutherford's Atomic Model of Matter:

(1) has heavy, positively charged centers called nuclei, spread far from each other.

(Heavy because *some* of the alpha particles were scattered backward;

positively charged since the force was one of *repulsion*;

spread far from each other because *most* of the alpha particles were not scattered through large angles at all.)

(2) has electrons orbiting around these nuclei, held in orbit by the force of attraction between the positive and the negative charges.

The trouble with the Rutherford Model:

All that was known in physics before 1910 seemed to indicate that all accelerating charged particles emit radiation, thereby losing energy. It has been calculated that the electron would not maintain its orbit, and would spiral down into the nucleus in about 10^{-11} second, while giving off a continuous spectrum of frequency of light, each particular frequency depending on the instantaneous energy of the particle at that time.

But not only don't atoms collapse in the manner mentioned above, they emit a discrete set of frequency lines for their spectrum, not a continuous spectrum. So the Rutherford model is inadequate.

Outline to Lecture 27

Planck made the assumption that light is emitted in "bundles", called photons, with energy hf, where

f is the frequency of the light and
h is a constant, called Planck's constant.

The Photoelectric Effect:
Certain electromagnetic waves cause electrons to be expelled from certain metals.

(a) Whether the light will or will not expel electrons for a given metal depends on the frequency of the light, but not on its intensity. If light has a high enough frequency to eject electrons, however, then more are ejected by a higher intensity beam.

(b) The minimum frequency necessary to eject electrons varies from one target material to another.

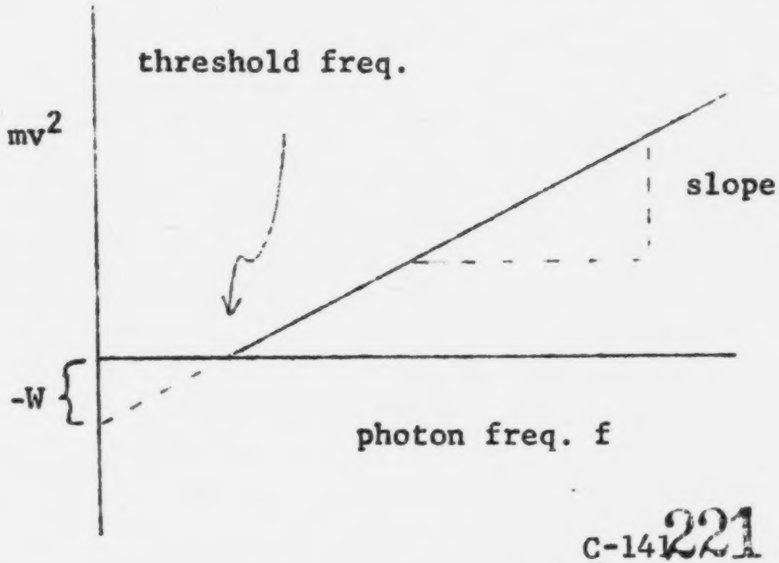
Einstein's explanation for the Photoelectric Effect:

(1) Light exists in bundles, each of which carries a discrete energy, $E = hf$.

(2) These bundles interact individually with electrons, giving an electron enough or more than enough energy to become free of the surface only if the energy bundle (hence, frequency) is large enough.

(3) There is a necessary amount of energy required to work the electron from the metal. It is given the symbol W.

(4) The Einstein equation: $hf = W + \frac{1}{2} mv^2$



De Broglie's Hypothesis:

Since light, which we have decided acts like a wave in some instances also acts like a particle in some other instances, perhaps things which we usually think of as a particle also have wave properties under some circumstances.

$$\text{momentum} = mv = \frac{h}{L}$$

therefore, for a particle, its "wavelength" is

$$L = \frac{h}{mv}$$

A photon of energy hf has momentum of magnitude:

$$\boxed{\text{momentum} = \frac{hf}{c} = \frac{h}{L}}$$

where h = Planck's constant
f = frequency of the photon
c = velocity of light
L = wavelength of the photon

De Broglie was thus inspired to guess that if particles had wavelengths associated with them, these wavelengths would obey the same equation.

$$\boxed{L = \frac{h}{\text{momentum}}}$$

In an important experiment, Davisson and Germer showed that a beam of electrons does show destructive interference, which is a property of waves. They also showed that the effective wavelength of these electrons, as calculated from the interference pattern, was just that predicted by the de Broglie relation!

If you go to the trouble of calculating wavelengths for most of the things you can think of, their wavelengths will be incredibly small, because h is quite small and the momenta involved will be quite large. However, electrons are so small that their momenta are also small, so their wavelengths were large enough to observe in the experiment mentioned above.

Complementarity:

In our ordinary experience, things act like particles or like waves. Our experiments at the atomic level show us that our ordinary experience with Newton's particle mechanics is not an adequate guide. We really have no reason to expect that things as small as photons or electrons will behave like things which are large enough to see. When we try to explain these phenomena, we are forced by our own limitations to try to make analogies with things we can see, but we should not be too disappointed if we need unfamiliar combinations of these properties to properly describe the unfamiliar phenomena.

Outline of Lecture 28

Review of the Bohr Atom

A nucleus surrounded by electrons occupying precisely specified orbits, each orbit having a different energy associated with it. This energy, of the electron in a particular orbit is just the electron's kinetic energy in this orbit plus its potential energy due to the electric field that it experiences in this orbit.

We can characterize an orbit by giving its radius or by giving its energy. The energy is more often used since it is more simply related to the frequency of radiation emitted during a drop in energy level or absorbed during a jump in energy level.

$$(1) \quad f = \frac{E_n - E_1}{h}$$

$$(2) \quad E_n = -\frac{13.6 \text{ e.v.}}{n^2} \qquad n = 1, 2, 3, ---$$

$$(3) \quad f = \frac{13.6 \text{ e.v.}}{h}\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

While the orbital radii increase in size indefinitely, the energies of these orbits approach a maximum value no matter how large the radius becomes.

If an orbiting electron is struck by another electron or given energy by a photon, it can:

(1) go to a higher energy orbit if it receives exactly the right amount of energy (excited atom).

(2) Travel outward leaving the nucleus and the atom (ionized atom).

For atomic emission of a photon:

$$E_2 - E_1 = hf_{21}$$

$$E_3 - E_1 = hf_{31}$$

$$E_j - E_i = hf_{ji}$$

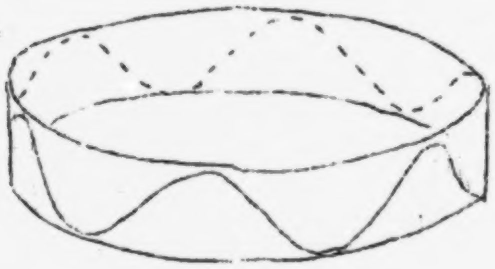
where E_i is the energy of the i^{th} orbit h is Planck's constant and f_{ji} is the frequency of the photon given off when an electron drops off from the higher E_j energy orbit to the lower E_i energy orbit.

These equations also hold for the absorption of a photon resulting in an electron jump in energy level.

Since f x L = C = speed of a photon

then $\Delta E = \frac{hc}{L}$

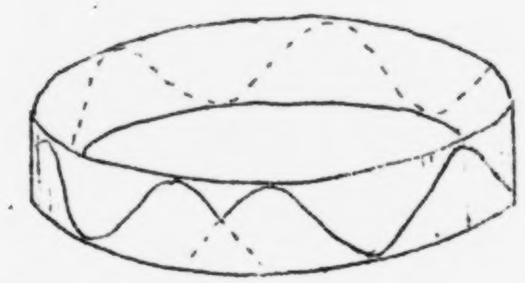
Figure 1a.



allowable

$2\pi r = 6L$

Figure 1b.



not - allowable

$2\pi r = 6.5L$

This closing is expressed by the equation:

$$n L = 2 \pi r$$

where n is any positive integer
L is the electron's wavelength
$2\pi r$ is the circumference of the orbit.

so $$\frac{nh}{mv} = 2 \pi r. \qquad (1)$$

Computation of the Orbital Energies

Two conditions relate the velocity to the radius of the orbit on which a charged particle travels around the nucleus. Because the Coulomb force must provide the necessary deflecting force to keep the particle on the orbit, we have

$$\frac{mv^2}{r} = \frac{kq_1q_2}{r^2}$$

$$mv^2 = \frac{kq_1q_2}{r} \qquad (2)$$

where q_1 = charge of the electron
q_2 = charge of nucleus
m = mass of electron
K = proportionality constant in Coulomb's force law

r = radius of the electron's orbit
v = velocity of the electron in orbit

Now, remember the de Broglie wavelength for a particle as defined in the last lecture is:

$$L = \frac{h}{mv}$$

L = de Broglie wavelength
h = Planck's constant
mv = momentum of particle.

If our electron has a stable orbit and a definite momentum, the last equation tells us it also has a definite wavelength. This will only be true if there are no irregularities in the interference pattern of the electron's wave around the orbit. We can assure this if we require that once the wave gets around the orbit it closes smoothly with itself as in figure 1a, in contrast to figure 1b, in which the circumference is of such a length that it does not contain an integral number of wavelengths.

By combining equations (1) and (2), we get

$$\left[mv^2\right]\left[\frac{nh}{mv}\right] = \left[\frac{kq_1q_2}{r}\right]\left[2\pi r\right]$$

or $$nhv = 2\pi kq_1q_2$$

This gives us the possible speeds of the orbiting particle:

$$v = \frac{2\pi kq_1q_2}{nh} \quad \text{where } n = 1, 2, 3 \ldots . \qquad (3)$$

On substituting (3) into (1), we obtain the corresponding radii of the orbits

$$r = \frac{nh}{2\pi mv} = \frac{n^2h^2}{(2\pi)^2mkq_1q_2} \qquad (4)$$

where n = 1, 2, 3 . . . .

The total energy of the orbiting electron is

E = kinetic energy + potential energy

$$E = (\tfrac{1}{2}mv^2) + (-kq_1q_2/r).$$

On putting the possible values of v from (3) into $\frac{1}{2}mv^2$ and the corresponding values of r from (4) into $\frac{-kq_1q_2}{r}$, we obtain for the possible total electron energies:

$$E = -\tfrac{1}{2}m\left(\frac{2\pi kq_1q_2}{nh}\right)^2 \qquad (5)$$

If we put the numerical values of the constants in this equation, we find that the energy levels predicted by this equation are exactly those which would account for all of the observable spectrum lines of hydrogen. (If you don't remember these lines, glance at chapter 6.4 of Van Name again.)

So this model of the atom has enabled us to find all the allowed radii and velocities for electrons in a hydrogen atom, as well as all the energy levels of the hydrogen atom and all of the spectral lines it emits.

FILM REVIEW: THE FRANCK-HERTZ EXPERIMENT (#421)

This famous experiment demonstrates that a substance absorbs energy packets of only certain sizes, and these energy values correspond to certain lines in the absorption spectrum of the substance. Furthermore, the substance emits energy, also, only in these same size packets--as shown by the fact that the mission spectrum has lines of the frequencies corresponding to these energy packets, as related by the formula, $E = hf$. The substance used in this experiment is mercury, the absorbed energy comes from the kinetic energy of electrons which collide with the mercury atoms.

This experiment was an important verification of Bohr's theory of quantitized orbits. But the experimenters did not even know of Bohr's theory at the time--as Dr. Franck tells you in his talk at the end of the movie. Incidentally, Dr. Franck visited the FSU campus just a few years ago as an honored guest, giving students and faculty a rare opportunity to meet one of the pioneers of modern physics.

The film involves considerable explanation of the techniques used, but don't lose track of the main idea as outlined above. It is the quantitization of energy absorption of the mercury vapor (4.9 electron-volts is a quantity of energy). This amount of energy corresponds to a frequency f given by $f = 4.9 \frac{\text{electron volts}}{h}$, and this in turn corresponds to a wavelength $L = \frac{c}{f}$, where c is the speed of light. The valve for the wavelength turns out to be 2537×10^{-10} meters, the same as the experimentally observed line in the emission and absorption spectrum of mercury. This correspondence marked a big step forward in man's understanding of the atom.

Now, please go to your terminal for a lecture quiz, then view the film.

Outline to Lecture 29

Quantum Mechanics:

(i) The motion of all matter, as well as energy, can be described in terms of the mathematical theory of wave propagation.

(ii) Matter waves for moving macroscopic objects have far smaller wavelengths than ordinary light. As you, hopefully, recall from the demonstration loops in lesson 9, interference and diffraction effects can only be observed with obstacles or slits of size comparable to or less than the wavelength under consideration. It is difficult to observe these effects with electrons, protons, and and so on. Since macroscopic objects are much, much larger than electrons, their wavelengths are so small that we cannot observe any interference effects.

(iii) All matter interacts with other matter by giving or taking energy in bundles (quanta). That is, it interacts like a particle. The energy bundles are so small though, that for large systems energy changes appear continuous. Only in very small systems, like the atom, is it necessary to take the quantitized nature of the interactions into account.

(iv) Quantum mechanics, as well as giving a complete description of the atom, has been useful in studying the nucleus.

#17 FUN AND GAMES USING INERTIA I

OBJECTIVE

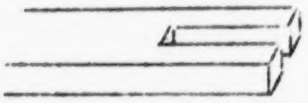
To illustrate the principle of inertia.

BASIC THEORY

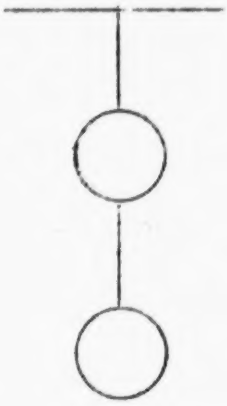
The Principle of Inertia: An object at rest (or in uniform motion) tends to remain in that state - unless a resultant force acts on the object.

Newton's Second Principle: The relationship between the force and the acceleration of a mass m is $F = ma$.

DEMONSTRATION APPARATUS



slotted board



2 balls of equal weight

DEMONSTRATION PROCEDURE

In each case below, the board is placed over top of the lower ball.

1 A steady push with increasing force is applied to the top of the board.

The string breaks above the upper ball.

2 Next, the board is hit a hard blow with a hammer.

The string breaks between the two balls!

In this second case, a large force on the upper ball is required to produce the large acceleration given to the lower ball. Therefore, the string breaks when the tension in it exceeds its breaking point.

CONCLUSION

In your own words, how is the principle of inertia illustrated in these two cases?

APPENDIX D

EXAMPLES OF READING QUIZ QUESTIONS

Lesson 3

Textbook Quiz

1. We had a system in which the standard units of measurement were the dustpan, the broom and the mop. If we multiplied one dustpan per broom^2 by two brooms, we would have:

a. 1 mop	c. 2 mops
b. 2 dustpans per broom	d. 2 brooms^2 per dustpan

(ca) b. Good! You understand the principle of cancelling units.

a,c,d. You don't yet understand how units are cancelled. Consult page 26 in your text, Van Name, Jr.

2. Which statement is true?

a. A yard is slightly over one meter.
b. A kilometer is greater than a mile.
c. A meter is slightly over a yard.
d. A micrometer is greater than a millimeter.

(ca) c. Fine.

a,b,d. You blew your cool on that one.

3. The conversion factor between centimeters and inches:

a. 1 inch = 2.54 cm.	c. 1 inch = 25 cm.
b. 1 cm. = 2.54 inches	d. 1 cm. = 25 inches

b,c,d. No, better review your material. This is rather important in that it gives you an idea of what a centimeter is.

(ca) a. Good.

4. In our physics course, the standard of length is the _______.

answer: meter

(ca) Very good!

(wa) No, we use the METER as the standard of length in physics.

5. How many centimeters are in a meter? (Type in your answer as a number.)

answer: 100

Lesson 5

Textbook Quiz

1. Zero degrees in the absolute temperature scale (Kelvin) corresponds to __________ degrees celsius (centigrade).

(ca) -273^o

That's right; pretty cold, isn't it? Let's try another question.

(wa) No, 0^o K = -273^o C.

hint This is one of those things you'll just have to memorize.

2. When using the ideal gas law, temperature must be measured in the __________ scale.

(ca) Kelvin or absolute.

Very good.

(wa) Wrong. In order for the formulation of the ideal gas law to work, temperature must be measured in the absolute scale.

3. The triple point of a phase diagram occurs at that temperature and pressure at which:

   a. All the material will be a gas at higher temperatures.
   b. The solid, liquid, and vapor pressures exist in equilibrium.
   c. Absolute zero and high pressure.
   d. hint

d. The name "triple point" is a clue.

(ca) b. Very good. I'm glad that you look at the diagrams in your text.

a, c. Wrong. Answer b is the correct one. Let's go on.

4. The main reason for using ice in a cool drink rather than cold water is:

   a. because it floats
   b. because of the heat of fusion; a chunk of ice takes up a lot more heat than the same volume of cold water.
   c. because ice dilutes the drink less.

(ca) b. Very good. Scotch-on-the rocks, anyone?

a, c. Remember that it takes about 80 calories per gram to change ice to water at 0^o C.

APPENDIX E

AUDIO LECTURES

APPENDIX E

AUDIO LECTURES

Lesson 1 - Introduction

Welcome to the CAI Center's presentation of Physics 107. Since you probably are taking this course to satisfy basic division requirements and not because you are primarily interested in physics, we tried to make this course as convenient a way as possible for you to learn the physics you need to understand the science section in the Sunday newspaper, for example.

You're probably curious about the procedure used to present the course, since there will not be any formal lecture attendance. First of all, you can proceed as fast as you wish through the course; if you finish in two weeks, fine. The only time requirement is that you must take the exams before certain dates. The proctor will give you those dates. Speaking of exams, there will be two of them, a mid-term and a final. You may take them as soon as you wish, but only once. The final will count for twice as much as the mid-term. Your grade will be recorded, so you'll want to be well prepared before taking the exams.

At the end of each of the 29 lessons, you will be given a reading assignment in your textbook, Elementary Physics, by F.W. VanName, Jr. At the beginning of the next lesson, a brief reading comprehension quiz will be given to you. If you fail the reading quiz, you will be asked to reread the material before continuing.

The course material is presented by four devices; a taped lecture, an IBM terminal, a four-minute film loop projector, and a regular 16mm film projector. The material presented by each of these devices is an important part of the course, not just a supplement.

You will be taught the care and feeding of the projectors by the proctor, and the IBM terminal operating technique will be taught by the terminal itself at the end of this lesson.

You make your own schedule for coming here for each lesson. All you do is call the Center and make appointments with the secretaries. There are no schedule conflicts around here.

Now that we've discussed the way the course is to be presented, let's go on and see what physics is and what a physicist does. Physics is the fundamental science of the natural world, which deals with time, space, matter, and motion. We will define it as the study of the motion of matter through time and space. I repeat: physics is the study of the motion of matter through time and space. The physicist observes these phenomena and measures them in order to understand and describe them. Naturally, the physicist needs tools to do these things. He needs special extensions of his senses to observe certain phenomena, like radio waves, atomic collisions, and the flow of electricity along a wire. He needs a system of measurement so that he can tell other people exactly what he observed. These measurements are expressed through numbers. The physicist uses mathematics as a powerful tool to clarify and classify his measurements and express relationships. Indeed, mathematics is the language the physicist uses in describing and understanding physical phenomena.

Now a few words about measurement. Measurement is essentially a counting process in which the magnitude of the unknown quantity is determined by comparison with a standard magnitude. Obviously, physicists need a convenient and reproducible system of units of measurement. The metric system, which satisfies these requirements, is the one used in science. In this course, length will be measured in meters, the amount of matter in kilograms, and time in seconds. This particular metric system of units is sometimes called the MKS system for short -- the first letters of meter, kilogram and second.

Now, a few more words about what a physicist does. He describes what we see. From this, he formulates a theory in order to attempt to predict future occurrences. If the predictions are repeatedly correct, we call the theory a law.

These quantities -- length, mass, and time -- are among the most basic notions in physics. They are important for you to remember, because combinations of their basic units can be used to express other physical quantities. For example, speed can be measured in meters per second. As you go through the course, you will find that the units of even less obvious quantities, such as force, energy, and momentum, can be expressed in terms of these three units. In fact, all other quantities you'll work with will be expressible in these terms until we begin the study of electricity, when we will have to add one more basic quantity: electric charge.

Let's recap what we've talked about. The primary tasks of a physicist are to observe, measure, understand and describe the phenomena of the natural world. His tools are mathematics and a system of measurement. Three fundamental quantities are: amount of matter, length, and time, and we measure these quantities in the units of kilograms, meters, and seconds.

For the first few lessons we will be teaching you about some of the tools and methods you will need in your study of physics.

Now, please inform the proctor that you are finished with the lecture - then continue your lesson at the terminal.

Lecture 2 - Measurement and Scientific Notation

Today we're going to learn how to handle large and small numbers. We will learn to use a different way of writing such numbers that makes working with them simple. For example, 1,000,000,000,000 - that's one trillion - has 12 zeros. It takes time and lots of paper to write that. However, that's the same thing as 10 multiplied by itself 12 times. How do we get this? Well, you should know that 10 to the second power - that's 10 squared - is 10 x 10, or 100, so by extension, 1,000,000,000,000 is 10^{12}. Your reading assignment for today told you something about working with exponents, and you'll find more about this subject in your supplement to today's lesson. Doesn't the 10^{12} notation seem simpler in terms of time and paper?

Suppose now that we have a number that isn't a simple multiple of 10, such as 7,360,000. How can we write that in a simple form? We see that there are four zeros after the 736, so let's start by writing 10^4. If we multiply 10^4 by 736, we have 736×10^4, or 7,360,000. (If you don't believe this, multiply it out yourself.)

But this is still a little offensive to our taste, and we decide we'd like to simplify things still further. More specifically, we decide it would be nice to always work with numbers between 1 and 10. This is impossible, of course, but it turns out we can do something almost as good: we can express any number in terms of a number between 1 and 10. And how do we do this? Simply by an extension of what we've just done. In our last example, for instance, we just showed that 7,360,000 is equal to 736×10^4. But 736 is itself simply equal to 7.36×10^2. (Multiply that out if you don't believe it.) So what we have in essence is $[7.36 \times 10^2$ times $1 \times 10^4]$. This product is equal to 7.36×10^6. (If you don't understand how this product is formed, consult your supplement. It gives some useful information about exponents and power laws.

So, finally, we have that 7,360,000 is equal to 7.36×10^6, in scientific notation. We say that we have a coefficient - that's the part between 1 and 10 - which is multiplied by a power of 10. In the example we just went through, the coefficient is 7.36 and the power of ten is 10^6. Let's now make some simple rules for writing large numbers in scientific notation.

1) Move the decimal point from its original location to one place to the right of the first digit. (Notice that this means you will actually be moving it from right to left.)

2) Count the number of digits from the original decimal point to the new decimal point after the first digit. This is the power of ten that is used.

3) The coefficient may sometimes be rounded off. For example: 409,000 may be expressed as 4.09×10^5 or 4.1×10^5, depending on the accuracy desired.

There are some typical examples in figure 1 of your supplement. For small numbers, the procedure is essentially the same, except that the decimal point is moved from left to right, and the exponent is negative. For example: .00012 is equal to 1.2×10^{-4}. Again, 1.2 is the coefficient, while 10^{-4} is the power of ten. You may wonder why the exponent is negative. Well, this is simply a matter of definition: X to the nth power is defined as 1 over X to the nth power, or 1 divided by X to the nth power.

Now, to take a very simple example: .1 in scientific notation is 1×10^{-1}. But we have just said that 10^{-1} is equal to $\frac{1}{10^1}$ or $\frac{1}{10}$, and $\frac{1}{10} = .1$. Similarly, $.01 = 1 \times 10^{-2} = 1 \times \frac{1}{10^2} = 1 \times \frac{1}{100} = 1 \times .01$. This principle may be, and is, then extended to more complicated examples such as those shown in figure 2 of your supplement.

If all this still seems a bit mysterious to you, study your lesson 3 supplement carefully when you get a chance. It contains all the information you will need.

The question now arises: how can we add, subtract, multiply and divide numbers written this way? Let's state some rules:

1) To add or subtract, the power of ten of both numbers must be the same. If they are not the same originally, convert them in such a way as to accomplish this; then add or subtract the coefficients of the two numbers, as required, and use the common power of ten for the answer. If necessary, then convert the final answer to proper scientific notation. There are some examples in figure 3 of the supplement.

2) To multiply, first multiply the two (or more) coefficients together, then add the exponents. If necessary, convert the final answer to proper notation. For examples, see figure 4 of the supplement.

3) To divide, first divide the coefficients; then subtract the power of ten of the divisor (that's the bottom number) from the power of ten of the dividend (top number). Put the final answer in proper form. Look at the example of figure 5.

Now that wasn't hard, was it?

There is one other thing you should know about. This is the so-called "order of magnitude" of a number. The order of magnitude is an expression which gives you an idea of the approximate or relative size of a number. For example, if we tell you that the diameter of a typical atom is about 2.5×10^{-14} meters, unless you're a nuclear physicist, that probably doesn't mean much to you since you're not used to dealing with such small numbers. But if we tell you that the diameter of a proton is of the order of 10^{-15} m while the diameter of a complete atom is of the order of 10^{-10} m, you can at least get a good idea of their relative sizes. We can, for instance, divide the diameter of the atom by the diameter of a proton, giving us $10^{-10}/10^{-15} = 10^5$. Thus, the atom is 10^5, or 100,000 times "wider" than a proton. That's quite a difference! Incidently, you don't have to remember these numbers; this is simply an example of what order of magnitude notation is good for.

Well, now that we know what it is, how do we go about finding it? It is found as follows:

1) Express the number in correct scientific notation with a coefficient and a power of ten, just as we have been doing all along.

2) If the coefficient is under 5, round it off to one and keep the same power-of-ten you already have. For an example, see figure 6.

3) If the coefficient is 5 or over, round it off to 10. Then you must again express the complete number in correct scientific notation. This means that the order of magnitude will be one power higher than the one you started out with. For example, say we want to know the order of magnitude of 5×10^8. We round off the 5 to ten, so that we now have 10×10^8. But this, expressed in correct scientific notation, is 1×10^9. Thus, our order of magnitude is 10^9. Similarly 6×10^6, 8.5×10^6, and 9.995×10^6 all have orders of magnitude of 10^7. We say that all these numbers are of the same order of magnitude, even though they have quite different values.

Some further examples are in figure 7.

If negative exponents are involved, as in the last two examples, the procedure is exactly the same; it just looks a little trickier and is a little bit more conducive to careless mistakes. You just have to keep in mind the rules for multiplying numbers which have negative exponents. Consult your supplement if you have doubts on this subject or need a review.

Now that you've learned about scientific notation and order of magnitude, report to terminal for a short practice session on this material.

Lesson 3 - Scaling

Today we're going to consider functions, power laws, and the problems involved with scale models. Let's tackle functions first.

When we say that A is a linear function of B, or A is proportional to B, we mean that the value of A is dependent on the value of B, in the same way as, for example, the weight of a solid piece of iron is dependent on its volume. If you double the volume of the piece of iron its weight is doubled; if you triple the volume, the weight is tripled. Or, in the general case where A is a function of B: If we double B, the value of A is doubled; if we triple B, the value of A is tripled. This is a simple example of what we call a linear function.

There is another kind of function which we call an inverse function. In this type of relationship, we say that A is proportional to $\frac{1}{B}$. As B is doubled, A is halved; as B is tripled, A is cut to one third. To give a not strictly scientific example; Let's say you are having a dinner party and have prepared just enough food for the number of invited guests, and twice as many people show up as expected. If you decide not to throw the party crashers out, you then have to cut down the portion of food allotted per person to one half of what it was. In this case, an inverse relationship existed between the amount of food served per person and the number of people present.

There is a third kind of function, called a quadratic function, of which the following is an example: The statement "P varies as Q^2" means that when Q increases by a factor of 3, P will increase by a factor of 9, since $3^2 = 9$. In other words, a quadratic function is one in which one variable varies as the square of another. An example of the kind of relationship we just described would be: if linear dimensions are changed by a constant scale factor, then area is proportional to the square of the scale factor.

You'll learn what we mean by a scale factor in a minute. For now, two other important relationships to keep in mind are:

1) If the linear dimensions of an object are all changed by the same scale factor, then the new volume is equal to the old volume multiplied by the cube of the scale factor. (This, by the way, is an example of a cubic function in which the value of one variable depends upon the cube of another.)

2) Since weight is proportional to volume (we already touched on this briefly, remember?) we can say that under the same conditions just described, weight is proportional to the cube of the scale factor.

Power functions can also be inverse functions, such as:

$$A \propto \frac{1}{B^2} \qquad P \propto \frac{1}{Q^3}$$

$$X \propto \frac{1}{Y^9}$$

Incidentally, if you are having trouble keeping up here, it might be a good idea to review some of the information on exponents and power laws that was covered in the last lesson. Section 1.5 of your text and the supplement to lesson 2 will be helpful to you.

All right, we've already introduced the term scale factor, so now let's go on to the subject of scaling and give you a better idea of what this means. Scaling involves the physical properties of so-called scale models, either larger or smaller than the actual object. Do you recall the movie about the oversized ape? You will soon see that he actually would have been unable to pick himself up off the ground, much less to perform his famous feat of climbing the Empire State Building.

First of all, let's see what we can say about a physical object whose dimensions (length, width, and height) have all been multiplied (or scaled) by the same factor. We will call this factor the scale factor and designate it by X.

We can say something about the following geometrical properties in terms of X:

length
surface area
cross-sectional area
volume

and the following related properties;

weight (related to volume)
strength (related to cross-sectional area).

Now let's see what effect scaling has on these various properties of an object. Let's take length first. Length has only one dimension, so if we multiply a length "ℓ" by a scaling factor "x", we simply have ℓx, and it's pretty obvious that length is proportional to x, or is a linear function of x. That one was easy.

Now let's consider how an area changes if we multiply each of its two dimensions by a scale factor x. Look at figure 1 and pretend you are laying tiles, each of which is 1 long and w wide. The area A of one tile is therefore A = (1) · (w) (figure 1-a). Suppose you then lay a pattern as shown in figure 1-b with a length of 3 tiles and a width of 3 tiles. The area A' of this pattern has the same shape as the original one tile; each dimension is three times as large (that is, length 3ℓ and width = 3w), but the area is nine times the original area. In other words, if an area is scaled up (or down) by a scaling factor x, keeping all proportions the same, the area is proportional to the square of the scaling factor.

Now how about volume? Well, volume is equal to length (λ) times width (w) times height (h), so if we multiply each of these dimensions by x, we will have volume, $V = (\ x)(wx)(hx) = \lambda wh\,(x)(x)(x) = V$ is proportional to x^3. If you don't quite see this, turn to figure 2 of your supplement. In part a we have a cube, 2 units on each side (i.e., $\lambda = w = h = 2$), whose volume obviously equals 8 units. (Count the cubes in order to assure yourself of this.) In part b, the original cube has been scaled up by 2. This means that each dimension has been multiplied by 2, making it now 4 units on a side. Count the cubes. Its volume is now 64, or 8 times the original volume. But 8 is equal to $2 \cdot 2 \cdot 2$, or the cube of the scale factor. This is what we wanted to show.

Since weight is directly proportional to volume, we can also say that weight is proportional to the cube of the scale factor. This bit of information will come in handy later on.

In a similar manner it can be shown that cross-sectional area and surface area are proportional to the square of the scale factor, and that strength, being a function of cross-sectional area, is proportional to the square of the scale factor also. Consult your supplement (figures 3, 4, and 5) to see how this is done. It's also interesting to know that for biological systems, heat production is proportional to volume, and hence to x^3 and heat loss is proportional to area, and hence to x^2.

Now for an example. In the case of King Kong, let's assume he's 10 times bigger than the run-of-the-mill ape. That means $x = 10$. Now, how do all his physical properties change by being scaled up 10 times? Well, length $\propto x = 10$ = 10 times bigger

cross-sectional area $\propto x^2 = 10^2 = 100$ times

strength $\propto x^2$ which equals $10^2 = 100$ times

volume $\propto x^3$ which equals $10^3 = 1000$ times

weight $\propto x^3$ which equals $10^3 = 1000$ times

In other words, his weight has increased 1000 times, but his strength only increased 100 times. So we can sum up King Kong's physique by saying that, far from being a menace, he would be quite harmless. He'd probably need help in feeding himself, and he certainly wouldn't be able to support his own weight enough to stand up. So we don't have to worry about him any more.

In just a few moments, you are going to see a very entertaining film which will bring out some of the points we covered in this lecture. The main point to keep in mind is that when all the dimensions of an object are changed by the same factor, its physical characteristics may be tremendously altered even though its geometric relationships remain exactly the same. Now, before viewing this movie, tell your proctor you are ready for a review of today's lecture.

Lecture 4 - Vectors and Motion

You remember our definition of physics; it is the study of the motion of matter through time and space. Today we want to talk about the word "motion" in that definition.

Suppose I say that I will leave Tallahassee at 11:00 and drive for one hour; where will I be at 12:00? Quincy? Perry? Panacea? You can't tell, because I didn't say in what direction I'd be traveling. In discussing motion, we MUST give the direction. This is why we use vectors to describe motion. A vector has both magnitude and direction. (Not all quantities which have magnitude and direction are vectors, as I will show you later.) Look at figure 1a. The length of the line segment represents magnitude; the arrow and the orientation of the line show the direction.

We'll need a symbol to write down when discussing vectors. An arrow over a symbol indicates that it represents a vector, as shown on vector $\vec{A}$ in figure 1a. In some equations we'll deliberately leave off the vector arrow over a quantity, to indicate that we're talking about the magnitude only of the vector. A quantity that has magnitude but not direction is called a scalar. For example, speed is a scalar quantity; it measures only how fast an object is moving. Velocity, on the other hand, is a vector quantity; the word velocity includes both the magnitude (a speed) and direction of motion. Now, how do we perform the operations of addition, subtraction, multiplication, and division upon vectors? Vector algebra can be complicated, but we will simply use scale drawings, which will be adequate for our purposes, rather than using a lot of trigonometry.

We'll start with addition. Suppose I start at point P, in figure 1b, and want to go to point Q. The simplest way is to go direct, as in figure 1b. This direct path represents the displacement at the end of the trip. But I could arrive at point Q by a less direct route, as in figure 1c; this trip is equivalent to the straight trip; it has the same result. Adding vectors together is similar to adding trips. More specifically, take a vector $\vec{B}$ (as in figure 2a) and a vector $\vec{C}$ and add them together. This is expressed in the equation: $\vec{B} + \vec{C} = \vec{D}$ ($\vec{D}$ is called the resultant). Notice we could have drawn the vector $\vec{B}$ anywhere on the page, as long as we kept its length and direction the same; there is nothing to distinguish one part of the page from another. Adding the vectors is like taking trips B and C in succession; we can draw this on a page by placing one vector's "foot" at the head of the other vector, always maintaining the original length and direction of the two vectors, as shown in figure 2a. The resultant $\vec{D}$ is then simply drawn from the foot of the first vector to the head of the second vector (or to the head of the last vector, if there are more than two vectors to be added as in figure 2b). We could just as well have started by drawing $\vec{C}$, and adding $\vec{B}$; this would give the same resultant as starting with $\vec{B}$ and adding $\vec{C}$. That is because vector algebra is commutative, which means that $\vec{C} + \vec{B} = \vec{B} + \vec{C}$.

Here's an example of something with magnitude and direction which is NOT a vector; rotations. Suppose we take a book and rotate it, first 90° about a vertical axis, then 90° about a horizontal axis, and note its final position. Then start the book from its initial position again, and perform the same two rotations, but in opposite order. The book ends up in a different position from the final position of the first set of rotations. Try this yourself with a book, after this lecture. Therefore, rotation is NOT a vector, because the order of adding is important.

The next operation is subtraction. Take the equation $\vec{B} - \vec{C} = \vec{E}$. As in addition, the equation is represented in our drawing by a triangle as in figure 4. One way to do this is to rewrite the equation as $\vec{B} + (-\vec{C}) = \vec{E}$. We can do this because subtracting a vector is the same as adding a negative, so we are changing our subtraction problem into an addition problem. (Look for example at figure 5. (-A) is simply a vector of the same magnitude as A, but in the opposite direction.)

Next we'll talk about multiplication. Notice we will only, in this course, be multiplying vectors by scalars. Multiplication of vectors by vectors can be done in two different ways, which give two different answers. We will not be using this. Multiplication of a vector by a scalar is simply a short way to add, as it is in ordinary arithmetic. Look at figure 6. Add $\vec{A}$ to $\vec{A}$ and you get $2\vec{A}$; Add $\vec{A}$ to $\vec{A}$ to $\vec{A}$ and you get $3\vec{A}$, just following the same procedure as before, putting the foot of the second $\vec{A}$ on the head of the first $\vec{A}$, and so on. They are all in a straight line, since the A's all have the same direction. You get a vector three times as long as A and in the same direction. Similarly, 3 times $(-\vec{A})$ is equal to $-3\vec{A}$; and $\frac{1}{2}\vec{A}$ means a vector half as long as $\vec{A}$, in the same direction. This also shows that multiplication includes division; if you have to divide vector by a number, you simply multiply it by the reciprocal of that number, just as you do in ordinary arithmetic.

To sum up in a rule: $q(\vec{A})$ is a vector q times as long as $\vec{A}$ and in the same direction if q is positive or opposite direction if q is negative. Look back at figure 2a for a moment. Is the following statement true, if I leave off the vector arrows over the letters, which means we're only talking about the magnitudes of these vectors: B + C = D. No, it isn't. With apologies for the English units (I couldn't find a metric ruler); $\vec{B}$ is 15/16 inches long, $\vec{C}$ is 1.0 inch long, so the sum of the magnitudes of $\vec{B}$ and $\vec{C}$ is 1 and 15/16" long, whereas the magnitude of $\vec{D}$ is only 1 and 13/16" long. The equation would only be true for magnitudes if the vectors happened to be in the same direction. It IS true that vector $\vec{B}$ + vector $\vec{C}$ = Vector $\vec{D}$. The equation holds ONLY with the vector quantities, not the magnitudes, because the equation represents that triangle.

You can see that there are an infinite number of "paths," or combinations of vectors, which will end in the same resultant. One particular combination is most useful in many problems; this is the set of components at right-angles to each other, known as the Cartesian components. You have probably used these in geometry or trigonometry, when you worked with the x and y components, or "projections." Please look now at figure 3b. Suppose you have the vector I. There are an infinite number of different combinations of vectors which could add up to give this same resultant, but we will usually find it most convenient to use the path consisting of two components, $\vec{I}_x$ and $\vec{I}_y$, which are at right angles to each other. You can see from the figure that the vector equation $\vec{I} = \vec{I}_x + \vec{I}_y$ is true, Why are these particular components so useful? It is because in the study of motion, we frequently want to study the vertical and horizontal components separately, and these are at right angles to each other. Or in other cases, we may want to "resolve" a vector into components parallel and perpendicular to the motion; again, these components would be at right angles to each other. A useful relationship to keep in mind when working with these Cartesian or right-angle components is Pythagoras' theorem:

> In a right triangle, the square of the hypotenuse is equal to the sum of the squares of the other two sides.

This is handy in working out the equations for the magnitudes of the vectors, as shown at the bottom of figure 3. For instance, in the figure just above, you can see that the following relation would hold true for the magnitudes of the vectors:

$$I^2 = I^2_x + I^2_y .$$

Compare this equation to the vector equation $\vec{I} = \vec{I}_x + \vec{I}_y$.

Those of you who've had trigonometry will recognize that these magnitudes are also related by the following trigonometric functions, as shown at the top of figure 3: $I_x = I(\cos 0)$; $I_y = I(\sin 0)$.

Now we'll apply this vector algebra to the study of motion. You've had most of this in your reading of Van Name, section 2.4. An observer at a given point 0, called the origin, can measure distance and time; he can say what the location of a certain body is at a given time by observing how far it is from him, and in what direction. In other words, he specifies a certain vector quantity--since he gives the magnitude of the distance and the direction. This vector is given the name displacement vector, for which we'll use the symbol $\vec{r}$. If the body is moving, $\vec{r}$ will change with time, so we'll use the symbol r_1 for the displacement at a time t_1, r_2 at a time t_2, and so on. One more symbol is helpful; a shorthand notation for the change in a quantity. If we have values a_1, a_2, a_3, and so on, we'll use the notation $\Delta a = a_2 - a_1$ to represent the change in a. This Δ does not mean Δ times a, any more than the word "is" means i times s. Δ a is like a word, meaning "the change in a". It can be used with vector or scalar quantities. Similarly, the time interval between two observations at times t_1 and t_2 can be written: $\Delta t = t_2 - t_1$. The statement that the object has moved can be written as a change in the displacement vector, $\vec{r}$, as follows:

$$\Delta \vec{r} = \vec{r}_2 - \vec{r}_1$$

This is shown in figure 7. As you see, $\Delta \vec{r}$ is simply the vector you have to add to $\vec{r}_1$ to get $\vec{r}_2$.

The time rate of change of the displacement vector is the velocity, defined at $\vec{v} = \Delta \vec{r} / \Delta t$. Actually, this is the average velocity in this time interval Δt; the velocity could vary at different times within this time interval. From the definition of velocity; you can calculate that $\Delta \vec{r} = \vec{v}\ \Delta t$; and since $\vec{r}_2 = \vec{r}_1 + \Delta \vec{r}$, it follows that $\vec{r}_2 = \vec{r}_1 + \vec{v}\ \Delta t$. This is the most generally used form for these equations, because I need only tell you r_1 and v and you can figure where the observed object will be at any time Δt later than t_1. This equation isn't difficult to understand. For example, if I know a friend is at Perry at a certain time so that r_1 = 56 miles from Tallahassee, and he is traveling at a speed of 50 miles per hour, I figure that one hour later (Δt = 1 hour), his distance from Tallahassee will be r_2 = 56 + (50 mph)(1 hour) = 106 miles from Tallahassee.

Now to distinguish between average velocity and instantaneous velocity. My friend in the example above averaged 50 miles per hour, but part of the time his speed was only 15 miles per hour, which he made up by doing 85 miles per hour during a later part of the trip. If you'd split his trip up into smaller and smaller portions, measuring the speed during each small portion, you'd get a better and better description of the motion. The extreme case would be to make continuous observations, measuring the average velocity during each small portion, you'd get a better and better description of the motion. The extreme case would be to make continuous observations, measuring the average velocity during each small interval, Δt. If the instantaneous velocity is the limit of these average velocities for smaller and smaller intervals as you finally make the interval $\Delta t = 0$. If the symbol v_i is used for instantaneous velocity, the definition can be written as shown in figure 7, and it is read aloud like this: The instantaneous velocity is equal to the limit, as delta t approaches zero, of delta r over delta t.

A special case is that in which the instantaneous velocity $\vec{v}_i$ is equal to the average velocity $\vec{v}$ for every instant of the trip. If you'll draw some vectors and think about this situation for a while, you'll realize this must mean that the velocity is constant, both in magnitude and direction. The result then is straight-line, uniform motion.

This may seem to be a complicated approach to a simple problem. It is. What we're interested in presenting here is the approach to the problem, so we'll be ready to use this approach in more complicated problems.

In this age of the automobile, it will come as no surprise to you that acceleration means the time rate of change of velocity. The equation is:

$$\left\{\begin{array}{l}\Delta \vec{v} = \vec{a}\ \Delta t. \\ \vec{a} = \Delta \vec{v} / \Delta t\end{array}\right\}$$

There IS a difference as used here from ordinary usage, though, in that here we include direction changes as well as magnitude changes in velocity. A toy train going around a circular track at constant speed is accelerated because the direction of its velocity is constantly changing.

In this course, we will usually be concerned with problems in which the acceleration is constant. And two simple cases will cover the subject for our purposes: one in which the acceleration is parallel to the motion; this is called accelerated straight line motion, because the acceleration changes the speed, but not the direction of the motion. The other case is that in which the accelerated is perpendicular to the direction of motion, and thus changes the direction only, without changing the magnitude of the velocity. If this perpendicular acceleration is constant, the result will be circular motion.

A more general problem would be that in which the acceleration is neither exactly parallel or perpendicular to the motion. This is a case in which it is useful to divide the acceleration vector $\underline{a}$ into two right-angle components, $\vec{a}_1$ (which is perpendicular to the velocity) and $\vec{a}_{11}$ which is parallel to the velocity. These two components add up, vectorially, to $\vec{a}$. Our two special cases described above correspond to one component or the other being equal to zero.

Now please inform the proctor that you have finished with lecture 4, then continue your lesson at the terminal.

Lecture 5 - Matter and Its States

Since matter is an integral part of the physical world, with which the science of physics deals, it's going to be necessary for us to achieve some understanding of matter and its properties. We gain this understanding by asking three main questions.

1) What kind of matter do we have?
2) How much matter do we have?
3) What state is our matter in? (You'll learn later on what is meant by state.)

Let's tackle these questions one at a time.

The answer to the first question belongs to the realm of chemistry rather than of physics. From chemistry we know that all matter is made up, ultimately, of a limited number of so-called "elements," and it is chemistry too which tells us, how gold, for example, differs from mercury and how water, a compound, differs from both of these. We will not go further into this subject in this course.

More interesting from the physicists' point of view is our second question: how much matter do we have? Or, to ask the question in a more specific way: how can we go about measuring the quantity of matter which we have? This question is more difficult than it may seem at first. Just how do we go about answering it? O.K., it weighs 5 pounds on the corner of Call Street and Monroe. Does it weight 5 pounds on the moon? No. In fact, the weight of our piece of matter will even be different at different places on the earth. This is because weight is dependent on gravitational pull, and gravity differs slightly from place to place on the earth's surface (depending on the altitude). Later on in this course, we will give you a more rigorous definition of weight--the one accepted by the physicist--which will enable you to better understand this.

Since the weight of our chunk of matter varies with location, as we have seen, it isn't a good method of determining the amount of matter we have. Well, let's see, then, if volume is a good indicator. Suppose we have one cubic meter of our material: what will happen to it as we heat it? Here on earth the heat will cause it to expand, but this same amount of matter would occupy much more volume on the planet Venus, because of the high temperature there. As you probably know, if we heat it past its boiling point, it will even turn into a gas, and we will have much more than one cubic meter of it.

Well, we've put ourselves into a quandary: weight is no good and volume is subject to change as temperature changes. What does a physicist do in this case? He makes use of still another property of an object, called the mass, of which we made mention in the very first lesson. Mass is very closely related to weight (and you will learn more about this relationship in future lessons), but it has the property of remaining constant everywhere in space and under any and all temperature conditions. You will learn about other properties of mass in subsequent lessons. For now, it is sufficient to think of mass as that property which is used as a measure of quantity of matter present in a piece of material. Mass is measured on a beam balance (see diagram) as opposed to a spring scale (such as an ordinary bathroom scale). Please notice the difference between these two methods of measurement, as it is very important. It is as follows: the spring scale measures the pull of gravity on a body. Thus, as we have previously pointed out, the reading will differ slightly from place to place. On the other hand, the beam balance compares the gravitational pull on two different objects, and, since the arm of the balance is very narrow compared to the diameter of the earth, the two measurements can, for all practical purposes, be considered to be taken in the same place. So what we do when we measure an unknown mass on a beam balance is to compare it with a known mass whose value has been arbitrarily defined, to see whether it is heavier or lighter, and if so, by how much.

The known masses used for reference in the laboratory are a set of so-called "weights", which are multiples and submultiples of the kilogram, all of which have been carefully copied from an international standard kilogram which is kept in Paris.

Now that our first two questions about matter have been answered, we will go on to the third: what state is the matter in? The possible states are solid, liquid, and gaseous.

However, there's one point which may surprise you. The physicists' idea of what a solid is differs somewhat from that of the average layman. To a layman, a solid is anything which appears to be - - well, you know - - solid. To the physicist, however, it is a piece of matter which has a definite crystalline structure. It happens that most of the things you think of as solids are indeed solid, but some are not. There is one very common substance which you will be surprised to discover is really not a solid, since it lacks a distinct crystalline structure. But we'll keep you in suspense about that for the moment. Right now, you are going to have the opportunity to view a beautiful color film, "Crystals" - - that's PSSC film 113 - - which will tell you something about the solid state as the physicist defines it. Two main ideas about crystals are presented. They are:

1) Crystals are made of small, identical units, either atoms or molecules.

2) These units are arranged in a characteristic regular order. It is this "orderliness" which is responsible for the fact that crystals "cleave" -- that is break -- along certain characteristic planes.

Mr. Holden, the narrator of the film, will also show you something about how crystals are grown, and will demonstrate that crystals cannot be grown from a solution of one substance "seeded" (and you'll find out what we mean by that) with another substance. Characteristic geometry of crystals is responsible for this effect too.

Now go see PSSC film no. 113, "Crystals." After that, please go to the terminal for a review quiz on that film.

Now you know that in physics we consider only crystalline substances to be solids. An interesting substance that appears to be solid, but strictly speaking is not, is glass. It has no specific orderliness in its makeup, so it is not a crystal. We call such substances supercooled liquids. We won't consider liquids any more in this course, but will go on to gases.

The molecular model of a gas that we will develop is of historical interest because it was among the first successful models that physicists constructed. We will present it here because it is a straightforward example of how to construct a theoretical model of a real physical phenomenon. Physicists like to make models of things in order to make the understanding of them easier. The method they use in model construction is:

1) Make observations of the way the real thing behaves.
2) Invent a way of explaining and tying together the observations. This is the model.
3) Test the model by making predictions from it and then seeing by experiment whether the predictions are correct.

At this point, a warning about models is in order. We must remember that models are, in fact, only models, and are not the real thing. The model is only analogous and does not correspond absolutely to the phenomena described.

The procedure outlined above is the one we will use to construct the molecular model of gases.

What observations do we make when studying gases? If we have a coffee cup full of a gas in a still room, we know that the gas will not stay in the cup very long unless we put a light lid on the cup. An open bottle of perfume placed at one end of a room can soon be smelled at the other end. The gaseous vapor from the perfume diffuses, or spreads evenly throughout the room. If we heat the bottle, the perfume diffuses much more rapidly. The heat has increased the rate of vaporization, and, hence, diffusion throughout the room. So we observe that gases diffuse and heat speeds up the process.

The gas in an inflated balloon exerts a push on all parts of the inside of the rubber skin; this is what causes the balloon to keep its shape. Thus, gases exert pressure.

Gases also can be compressed to a very great extent. For example, an originally large volume of air fits inside the relatively small volume of an automobile tire. Or, enough air is compressed into the small volume of an aqua lung tank to allow a diver to breathe for up to an hour or so under water. So we observe that gases can be compressed very much more than liquids or solids.

Now that we have made some observations, we need to invent a model to tie them all together so that our observations are included or explained.

Let's assume that a gas is made up of tiny particles which we will call molecules. These molecules have extremely weak forces acting between them so that they are free to move about and diffuse. We'll also say that these molecules are separated from each other by distances which are about 10 times larger under ordinary conditions than the diameters of the molecules themselves. This is what makes it possible to compress the gas. To compress means to "squeeze" the molecules together, thereby reducing the distance between them.

We will also assume that the molecules are moving in random directions, with speeds which are a function of the gas temperature. These speeds are greater at higher temperatures, smaller at lower ones.

When the moving molecules collide with each other or hit the walls of their container, they interact elastically and don't lose any of their speed. Since the gas molecules are colliding with the walls of their container, they exert a push on the walls which we call pressure. The amount of push depends on the average speed of the molecules and the average number of molecules striking within a certain area per unit time.

Let's stop here and summarize what we have said about our model.

1) Gases consist of collections of molecules very weakly bonded together, which therefore move about readily and need a closed container to hold them.

2) These molecules are in a continuous state of random motion (the phenomenon of diffusion is a good proof of this).

3) The speeds with which the particles move are a function of the temperature, and are related to it in such a way that as the temperature of the gas increases, the average speed of the gas molecules increases.

4) Collisions of the molecules with each other or with the walls of their containers are perfectly elastic. This means that no speed or energy is lost in such collisions.

Now that we have our model of an ideal gas, let us apply it; that is, let us see how it can be used to account for the behavior of a real gas. We will be interested in three properties of the gas. These are the volume, the temperature, and the pressure. The meanings of volume and temperature are familiar. Pressure we will define as the force per unit area which a gas exerts on the wall of its container. You can see, therefore, that pressure is dependent on both the number of gas particles striking an area per unit time, and the speeds with which they are traveling.

We want to know the relationships between these three quantities (that is temperature, volume, and pressure) under two conditions which we will now proceed to describe.

Imagine that we have some gas contained in a hollow cylinder whose lid is a piston that can be moved up and down. We now push down on the piston, thus reducing the volume occupied by that same amount of gas. While we are doing this -- and this is very important -- we keep the temperature of the gas constant. What will happen? Well, if we had some sort of pressure gauge handy, we would discover that as the volume decreases the pressure increases; and similarly, if we move the piston up again, as the volume again increases, the pressure decreases. This certainly seems to make sense, just by analogy with everyday experience. You know that the more things you pack into a crowded suitcase, the greater the pressure that is exerted on the lid.

Our conclusion therefore is: the pressure exerted by a gas varies inversely as the volume, if the temperature is held constant. Or, we say, at constant temperature, $P \propto \frac{1}{V}$. Please notice that we are saying $P \propto \frac{1}{V}$, not $P = \frac{1}{V}$. What we mean by this is that as the pressure is doubled, the volume is halved, and so on. This is an example of the kind of inverse function we studied in lesson 3. The relationship $P \propto \frac{1}{V}$, incidentally, is known as Boyle's Law.

Now let's take another situation. Say we still have our gas in the piston (with our pressure gauge attached). This time, however, we hold the piston steady in the same position, but change the temperature of the cylinder and hence of the gas inside.

What will happen this time? It turns out that temperature increase causes an increase in pressure, while a temperature decrease will create a corresponding decrease of the pressure of the gas within the cylinder. It's easy to remember that increase in temperature is associated with increase in pressure if you keep in mind the fact that a toy balloon which has been left in the sun or otherwise heated, will expand (and often, pop!) This is not a completely good analogy to our constant volume situation, since in this case, the volume obviously does change. The point is, however, that it is the increased gas pressure, brought about by heating, that causes the expansion. If the balloon were made of iron, its dimensions wouldn't change much, and we'd have to resort to some other means to detect the pressure increase.

Therefore, we can conclude: if the volume occupied by a gas is held constant, then the pressure of the gas varies directly as the temperature. Or we say: for constant volume, $P \propto T$, or P is a linear function of T. (Remember linear functions from lesson 3?) This relationship is known as Charles' Law. (You don't need to remember that. The name, that is. Just remember the content!) It is very important to note here that, in gas law equations, temperature is always measured in the Kelvin, or absolute, scale. As was pointed out in your reading assignment, you can convert a Celsius (or Centigrade) temperature to absolute (or Kelvin) temperature by adding 273°.

The two main points about gases which you should keep in mind from our discussion are:

1) At constant temperature, pressure varies inversely as volume

and

2) At constant volume, pressure varies directly as temperature.

(These are Boyle's Law and Charles' Law, respectively.)

As you can see, it is possible to combine the two equations $P \propto \frac{1}{V}$ and $P \propto T$ to yield $P \propto \frac{T}{V}$, or $PV \propto T$.

You will not need to remember this result for this course. It is the two equations, individually, which you must be able to work with. And remember always to express T in the Kelvin, or absolute, scale, when working with gases.

Now I want you to look at film loop No. 80-296, entitled "Properties of Gas." In this film, you will see a very clever mechanical analogy of a gas. Read the explanation on the box carefully. It contains some things you haven't had before, so you won't be held responsible for it, but try to get as much out of it as you can. In particular, you should get a good idea of what a collection of particles in so-called "random motion" looks like. You should also be able to see and appreciate the relationship between pressure and number of particles present, and pressure and volume, both of which we've already discussed. The model you will see is two-dimensional; whereas the actual motion of gases takes place in three dimensions. Nevertheless, the principle is exactly the same.

Now look at the film loop 80-296, Properties of Gas. When you have finished, report to your terminal for a quiz on the contents of this lecture.

Lecture 6 - Light, Reflection, Refraction, Images

You saw in the film that there are four ways in which light is bent:

1) Reflection
2) Refraction
3) Scattering
4) Diffraction

Let's study reflection. You know what a plane mirror is; it's that thing over the bathroom sink that you hate to see your image in first thing every morning.

From reading your text book, you know that the angle of incidence, i, and the angle of reflection, r, are measured between the incident beam and the normal and the reflected beam and the normal, respectively. The normal is a constructed line perpendicular to the reflecting surface at the point of reflection. Figure 1 shows the reflection of a ray of light from a plane mirror.

You also remember from your textbook the two laws of reflection:

1. The incident ray, the normal, and the reflected ray all lie in the same plane.
2. The angle of incidence is equal to the angle of reflection. $i = r$

We can use these laws to find images formed by mirrors. This is accomplished by drawing ray diagrams and finding where the apparent origin of the rays lies behind the mirror. For example, we wish to find the image of a candle 50 centimeters in front of a plane mirror. First we draw the mirror and the candle as seen from the top. Go ahead and draw it, copying figure 2. As we develop this method, draw the lines, copying figure 2. Next, we draw a ray of light from the candle to the mirror so that $i - 0^o$ and, therefore $r = 0^o$. This is ray AB in figure 2. The reflected ray is extended behind the mirror since it appears to an observer to be coming from there.

We next draw a ray from the candle to some other point, C, on the mirror. There we construct the normal and measure i and then since $r = i$, we draw the reflected ray. This reflected ray is then extended behind the mirror as we did before. Where the two apparent rays cross, point D is where the apparent source of the reflected rays lies. Using careful construction, we can draw any number of rays from the candle to the mirror and all of the apparent extensions of the reflected rays will meet at point D.

Let's do a little plane geometry and save ourselves a lot of algebra to find out how far behind the mirror the image at point D lies. Look at the argument on figure 2 of your supplement.

The angle formed by DC and the normal at point C is equal to r because opposite interior angles are equal. Because $r = i$, the angle formed by DC and the normal is also equal to i.

The angle ACB is equal to $90^o - i$. Similarly, angle DCB is equal to $90^o - i$. So ACB = DCB. Angles ABC and DBC are both right angles and side BC is common to both triangle BCA and triangle BCD. We can now say that triangle BCA = triangle BCD because two angles and one side are common bo both of them.

Since the triangles are equal, line AB = line BC. This tells us that the image at D is as far behind the mirror as the object at A is in front of the mirror. Note that this proof did not use any specific values so this is a general rule.

We call this type of image a virtual image because no light rays actually pass through or originate at the image. From experience, you know that left and right sides of the virtual image are reversed. You correct automatically for this while shaving or fixing your hair. Such an image is a perverted image.

Is there any mirror that will form a real image, that is, an image located by actual light rays instead of extensions of actual light rays? Yes, there is. A real image is formed by certain curved mirrors, such as parabolas. We can construct such an image by saying each tiny point on the mirror where a ray is reflected is a very small plane mirror. Look at figure 3.

The normal at that point is the perpendicular of a tangent to the mirror at that point. Note that if we use parallel light rays from a distant source, they all cross at one point called the focal point. If a light source were put at this point, the light reflected from the mirror would form a narrow beam. This is the principle used in search lights and automobile headlights.

Now let's get into refraction. You should remember from the film what refraction is. It is the bending of the light path when traveling from one medium to another. We observe that when traveling from a less dense medium like air to a more dense medium like water, the path in water is bent toward the normal. This is shown in figure 4.

The angles of incidence (i) and refraction (r) are measured between the normal and the appropriate ray, similarly to the angle of reflection. As in the case of reflection the 2 rays and the normal all lie in the same plane.

When light travels from the more dense medium to the less dense medium, the bending is the reverse of the first case, the path in the less dense medium is bent away from the normal. See figure 5.

Is there a relationship between i and r for refraction? After this lecture you will see a demonstration in film loop FSU-24 on the relationship between i and r as i is varied from about 0 to 45 degrees. It will be obvious that i is not equal to r, otherwise, there would be no bending at the interface between the two media. Perhaps the ratio i/r is a constant for all values of i; but careful observation and measurement would show this ratio does not stay constant as i is varied over a wide range. So what, if anything, does stay constant as we vary i? A physicist named Snell discovered the answer. Look at figure 6 for a moment. Snell found out that there is a ratio that remained a constant for different values of i and r. He noticed that the ratio $\frac{AB}{PB}$ divided by the ratio $\frac{CD}{PC}$ is a constant called n. The method of writing the ratio $\frac{AB}{PB}$ is as sin i, and similarly $\frac{CD}{PC}$ as sin r, so we have $\frac{\sin i}{\sin r} = n$.

n is called the index of refraction and is different for different media. The index of refraction also changes slightly for different wave lengths of light. This causes white light to break up into a spectrum after being refracted through a prism.

Now that we have made these observations of how light behaves, the next task is the construction of a model of light, just as we did for gases last time. We will do this next time you come. For now, go look at Film Loop FSU-24 "Refraction and Reflection of Light;" then report to your terminal for a brief quiz.

Lecture 7 --

You have learned three things about light so far in this course. They are:

1) Light travels in straight lines.

2) When light is reflected, its angle of incidence is equal to its angle of reflection, (i = r), and both are in the same plane as the normal to the surface.

3) Light is "bent" when entering one transparent medium from another. This is called refraction and obeys Snell's law. The ratio sin i/sin r is a constant.

Now we wish to speculate on the real nature of light and propose a model that will explain its observed characteristics. Let's suppose for a moment, just as Isaac Newton did, that light is made of particles like tiny ball bearings. Can such a model explain the characteristics of light? Let's see.

1) Light travels in straight lines. If our particles moved very fast (3×10^8 meters/sec.), we would not notice their path's bending over distances. Remember, the faster a baseball is thrown, the less arc in its path. The particles of light must also be very small since we observe no interaction between two beams of light crossing each other or with air molecules. Therefore, the probability of particles hitting one another must be very small.

2) Light is refracted such that sin i/sin r = a constant index of refraction. This phenomenon is modeled by a steel ball rolling along a plane, then down an incline, which represents the surface of the new medium, and then along a lower plane, representing the second medium. Look at figure 2.

The ball's path bends towards the normal in such a model, just as light bends when entering water from air. The speed on both planes is constant, but the speed on the lower plane is faster than on the upper because of the acceleration received from the force of gravity at the boundary. However, the components of the velocity parallel to the boundary on both planes are equal as shown in the vector diagram in figure 3.

To demonstrate that a steel ball really does bend toward the normal in such an experiment, we have a film loop, FSU-23, to show you at the end of this lecture. It is called "Refraction and Reflection: Particle Model".

So far we have seen that the particle model of light seems to explain all of the observed characteristics of light. There is one other thing than can be explained by the particle model of light, intensity of illumination. Actually, that's rather obvious. The more particles which strike a surface per unit of time, the brighter the light incident on the surface.

If you were really sharp, you spotted that, using this model, refracted light particles, which bend toward the normal, travel faster in the new medium than in the old one. This is what is predicted by this model when light enters water from air. However, does light really travel faster in water than in air? The film you will see answers that question for you. First, however, please look at film loop FSU-23, then work through today's lecture quiz at the terminal to be sure you understand the material presented so far.

Lecture 8 - Reflection and Refraction of Waves

In the film on "Simple Waves", you saw that the speed of a wave depends on the nature of the medium, that waves can be reflected, and that waves can pass from one medium to another with partial transmission and partial reflection.

What are some of the physical quantities of waves that can be measured? Consider a wave train as drawn in figure 1.

This wave is traveling from left to right. The horizontal dotted line is the equilibrium position of the medium through which the wave is moving. The length (L) of a single wave can be measured by measuring the distance between any two consecutive corresponding points, such as two consecutive crests or troughs.

The time it takes a given wave to pass a stationary point is called the period (T) of the wave. For example, if a wave took 3 seconds to pass a given point, the period is 3 seconds per cycle.

The number of waves per second passing a stationary point is the frequency (f) of the wave and you should see that the reciprocal of the period is the frequency.

$$\frac{1}{T \text{ second/cycle}} = f \text{ cycle/second}$$

Since the period (T) is the time necessary for the wave to travel one wavelength, dividing this wavelength by T gives the distance that the wave will travel in one second. This distance is the speed of the wave.

$$V = L/T$$

Since $f = 1/T$, we can write

$$V = Lf$$

A special kind of wave is a regular series of straight pulses, such as would be set up by a ruler vibrating with a regular frequency in water. See figure 2. The lines represent successive crests, so the distance between them is the wavelength (L). The velocity vector for the wave-train is perpendicular to the straight wave-pulses. We will use this particular kind of wave to explore the reflection and refraction of waves because they are easy to visualize.

You saw waves reflect in the film when Dr. Shive was experimenting with slinkies. We have included a drawing in the supplement (figure 3) which shows a wave-train being reflected from a plane surface. You can see from figures 2 and 3a that the velocity vector of the wave is everywhere perpendicular to the wavefronts, so you may consider extensions of these velocity vectors as representing "rays". If we were talking about light waves, they would be light rays. A ray has been drawn in figure 3b.

You can see that the normal constructed between the incident ray and the reflected ray shows that the angle of incidence is equal to the angle of reflection. This happens every time, at every angle of incidence. The reason is that all parts of one of these wave pulses travel with the same velocity because they are in the same medium, water. If the pulse starts out straight, it remains straight until forced to bend by the interfact. But even then, the speed of the straight pulse remains the same, so a straight wave goes out just as far in its new direction as it would have continued in its old direction, if there were no interface. This is why the construction shown in figure 3a actually does give the right angle of reflection. So a wave picture of reflection can explain reflection as well as the particle picture we had previously considered.

In the film you saw that when a wave travels from one medium to another, its speed changes. However, the frequency doesn't change because it is dependent only on how fast the source of the wave is vibrating. I repeat: the frequency doesn't change because it depends only upon how fast the source is vibrating. If the frequency remains constant, no matter what the medium, and the speed decreases in going from a less dense to a more dense medium. This is found from the relationship:

$$V = LF$$

If F is constant, and V decreases, then L must decrease too.

Look at figure 4. This is a drawing of a train of straight wavepulses incident on a more dense medium, for example water, from a less dense medium, such as air, at a particular instant of time. The wavepulses are labeled 1, 2, and 3. Note the wavelength in air, L_a and the wavelength in water, L_W. The velocity vectors V_a and V_W are perpendicular to the wavepulses. The waves have a period T. Think for a moment what the drawing looked like T seconds ago. (Remember that in one period the waves travel one wavelength.) Wave 1 was where wave 2 is now.

If the speed of the pulses is less in water than in air, and the period remains constant, the point on wavepulse 1 which was at Q, T seconds ago, has moved to B in these T seconds. If we do this for all of the points on the wavefront as they cross the surface, we will see that the wavefront bends at the surface. In other words, once the wavepulse hits the interface all points on the pulse no longer travel with the same speed. Some go slower because now they are in the denser medium. The distance that these points travel in a given time is less than the distance the other points carry. And so, there is bending of the straight pulse, at the interface. Because of this bending, the velocity vector which is perpendicular to the wavefront also takes another direction. The velocity vector's new direction is closer to the normal than it was before hitting the surface. Since the light rays are in the same direction as the velocity vectors, the light rays must be closer to the normal than they were in air. But the prediction that light rays bend closer to the normal in water if light goes slower in water explains only part of the observation we made about refraction of light. What about Snell's law?

Now look at figures 5 and 6. We will use these diagrams to show how a wave model of light will correctly predict Snell's law. Figure 5 shows that the angle between the incident ray and the normal to the surface is equal to the angle between the incident wavefront and the surface itself. Since the angle between the incident ray and normal to the surface is what we mean by the "angle of incidence," these two equal angles have both been identified with an "i" in figure 5. Look at them.

Now look at figure 6. You see that the same angle, which was equal in size to the incident angle, has been again marked "i." Locate this angle and satisfy yourself that it is the same as in figure 5. In figure 6 you see that there is an angle marked "R." Now, figure 5 showed you that the angle between the incident ray and the normal was equal to the angle between the incident wavepulses and the interface. Since the refracted rays are also perpendicular to the refracted wavepulses and the normal on the other side of the interface is also perpendicular to the interface, the same argument as shown in figure 5 tells us that the angle "R" in fugure 6 is equal to the angle of refraction.

Now that you know that the angles i and R in figure 6 are equal to the angles of incidence and refraction, it is easy to get Snell's law from the diagram. We just write that:

$$\sin i = \frac{L_a}{PQ} \quad , \quad \sin R = \frac{L_w}{PQ}$$

Then $$\frac{\sin i}{\sin R} = \frac{L_a}{PQ} \times \frac{PQ}{L_w} = \frac{L_a}{L_w} = \text{constant.}$$

This relation, $\frac{\sin i}{\sin R}$ = constant, is Snell's law.

This wave model, unlike the particle model, does keep the velocities in air and water correct. You can see this again by remembering that $V = Lf$, so $V_a = L_a f$ and $V_w = L_w F$. So we can write our result down:

$$\frac{\sin i}{\sin r} = \frac{L_a}{L_w} = \frac{Va/F}{V_w/F} = \frac{V_a}{V_w}$$

This equation tells us, correctly, that, if the angle of incidence in air is greater than the angle of refraction, in water, then the velocity of the wavepulses in air is greater than the velocity of the wavepulses in water. Since the relationships shown here to hold for wavepulses all hold for light, we have strong evidence that light should be thought of as a wave phenomenon. Now, tell the proctor that you are through with this lecture and then do the lecture quiz at your terminal.

Lecture 9 - Interference of Light Waves

In the last lesson, we saw how the wave model of light explained both reflection and refraction and also predict correctly that light moves slower in water than in air. Today we're going to see some more evidence in favor of the wave model of light. However, in order to understand this new evidence, you are going to have to know about the principle of superposition.

Consider the wave train drawn in figure 1. It has a period, T, a frequency, F, a wavelength, L, and a velocity, V. There is another property it has which we have not discussed yet, namely its amplitude, A, seen labeled at the left side of the drawing. The amplitude of a wave is the distance from the undisturbed level of the medium to either the top of a crest or the bottom of a trough. The displacement, D, is something like the amplitude, except that while A is constant for a given wave, D measures the size of the disturbance from equilibrium at a particular point. D changes with time. Looking again at figure 1, note the several displacements shown, D_1, D_2, and D_3 is equal to A.

The superposition principle explains the behavior of two or more waves at the same place. It simply says that the displacements at the same location are additive. This means that if 2 displacements are at the same place at the same time, they add together to form one resultant displacement.

Let's consider several special cases of this phenomenon. First, when the crests and troughs of both waves exactly coincide, this coincidence is called being in phase. Figure 2 shows two waves that are in phase and the resultant wave that an observer would see. Their amplitudes are A_1 and A_2 respectively. The diagram also shows a representative set of displacements, D_1, D_2, and D_{12}, for illustration. When the waves are in phase as in figure 2, they are said to interfere constructively.

Figure 3 shows the opposite case. We again have 2 waves with the same wavelength L, but this time one crest is ½L behind the other. Since the displacements are in opposite directions, the magnitudes of the displacements subtract from one another so the resultant wave has smaller amplitude than would be caused by either wave alone. This is an example of what is called destructive interference.

More common than either of the two cases we have just mentioned would be the intermediate case, where the waves are neither exactly in phase nor ½ wavelength away from being in phase. These waves form resultant waves with characteristics between the two extreme cases we have mentioned. For an example of this, see figure 4. Not surprisingly, any waves which are not in phase are referred to as "out of phase."

An interesting case is two waves of equal amplitude, exactly ½L out of phase. The resultant will have zero amplitude since at any point the two displacement vectors will cancel. The medium will be completely undisturbed and it will appear as if no waves at all are present.

Having seen a theoretical discussion of what happens when waves are superimposed, you are now ready to see some concrete evidence that light wave interference actually does occur. You will now look at two film loops which demonstrate interference properties of light. First, look at film loop 80-241, which shows how interference between waves from point sources depends on their phase differences. Then look at the film loop on double-slit interference #80-207.

You saw patterns of light and dark bands and you also saw a formula, $\sin \Theta = \frac{m}{\quad}$, which described the pattern. There are interference maxima and minima which correspond to constructive and destructive interference, respectively. See figure 5. The centers of the bright bands on the screen correspond to places where the distances that the two waves travel are such that they interfere constructively. The centers of dark bands correspond to places where the distances which the two waves travel are such that they interfere destructively.

An interesting application of destructive interference is found in the non-reflecting glass used in black and white televisions. The human eye is most sensitive to light in the green portion of the spectrum. If a coating is applied to the glass so that the coating is one quarter wavelength of green light in thickness, destructive interference of the reflected light occurs. Part of the light that enters the coating is reflected from the glass and thus travels one-half wavelength by the time it reenters the air. It then interferes destructively with the part of this beam that is reflected from the surface of the coating. See figure 6.

An interesting question now occurs. Can such non-reflecting glass be used for color television? Think about it for a while. The answer is on your supplement as figure 7. I'll give you ½ minute.

If you read the material on the container of the double slit interference film loop, you were probably puzzled by the statement that "the relative intensity of the various maxima is governed by an envelope which is the single slit pattern of either slit." You have seen that diffraction is a way that light is distributed. You may wonder what this has to do with waves, and how in heaven's name you get a single slit pattern. The film loop called "Diffraction and Scattering Around Obstacles in a Ripple Tank" #80-244 will illustrate how waves are diffracted. It shows flat waves hitting an obstacle, as in figure 8 of the supplement. You see in this figure that the direction of the pulses is bent, just as some light rays seem to be bent when they go through a thin single slit. The amount of bending depends on the relative sizes of the wavelength and the obstacle. The film will give you an idea of how diffraction occurs at an obstacle. It also tells you how diffraction of light works for a thin slit. A thin slit is nothing more than two obstacles, like in figure 9. The smaller the slit relative to the wavelength, the greater the bending from diffraction as you saw in the demonstration. Now take a look at film loop 80-244 and also 80-206 on "Single Slit Diffraction," for proof that what our wave model predicts actually happens.

So now you know that a single slit produces a diffraction pattern which depends on its width and the wavelength of light. From the first part of the lecture, and also from Van Name, you saw that light from two coherent sources (such as two thin slits with a light behind them) gives an interference pattern which depends on how far the slits are apart and the wavelength of the light. So, in the double slit demonstration you saw, these different patterns were superimposed to give the final pattern you saw. The slits each had a diffraction pattern. The overlapping light from the two diffraction patterns interfered to give the final pattern you saw. This final pattern depended on all the things the diffraction patterns depended on, like wavelength and width of slits. It also would change if the distance between slits change, so it isn't just like a diffraction pattern. It was the superposition of the waves which caused the two diffraction patterns, and the waves which caused these patterns sometimes canceled each other at certain places. Now you know what that sentence I quoted meant. I repeat: the intensity of the various maxima of a double slit pattern is governed by an envelope which is the single-slit pattern of either slit. It says "either slit" because both slits were the same size and so had the same diffraction pattern.

Pretty complicated? Relax. You really don't have to remember how interference or diffraction patterns look, or what they depend on. What you should know is that equations which are derived from the wave model actually do describe these patterns. So here is something which the wave model explains and the particle model can't explain. In fact, we can now say that in as far as its propagation is concerned, light does act like a wave.

Do you understand this much? If you don't, there's no one stopping you from listening to the lecture or viewing the loops again. If you think you do understand, go ahead and take the lecture review quiz after telling the proctor that you have completed this lecture.

Lecture 10 - Forces

Later on in this course, we'll find that the wave model is unable to explain certain things that light does, and we will have to return to a dual wave-particle model. To do that we're going to have to learn how particles behave; therefore, we're now going to leave light and take up dynamics, the science of how forces affect the motion of particles.

So, what's a force? Good question. In simple terms, a force is a push or pull. You know that you can push a pencil across a table and the pencil will move in the direction you push it, if nothing is resisting its motion in that direction. You also know that you can push harder or softer on the pencil. This seemingly obvious discussion is leading to the idea that force is a vector quantity since it has both direction and magnitude. Don't forget that force is a vector quantity. You should remember from the lesson on vectors how to add vectors. If you don't, you had better review vector addition at the earliest opportunity.

Consider an object with two forces F_1 and F_2 acting on it as shown in figure 1a. In such a condition, it will appear to an observer and to the object as if only one force was acting. This single force is the vector sum of F_1 and F_2 shown Fnet in figure 1b. In more complicated cases where many forces are acting on the object, the object still acts as if only one force, the net or unbalanced force, is acting.

If you push on an object with an unbalanced force, the object will accelerate; if the object is at rest or moving with a constant velocity, there is no unbalanced force acting on it: Be careful not to interpret the last sentence to mean that no forces are acting at all. There may be a large number of forces acting, but their vector sum will be zero, therefore, no net force, no acceleration. From now on, when we say a force is acting on an object, we usually mean a net unbalanced force unless otherwise specified. If an object's velocity is not constant, which means its acceleration is not zero, there must be a net unbalanced force acting on it. An interesting example of this is an object moving in a circular path with constant speed - but not constant velocity, since the direction keeps changing, to follow the circular path. Therefore the body is accelerated. We know that the acceleration vector has no component in the direction of the velocity; if it did, the speed would change. So the acceleration is perpendicular to the velocity at each point of the circle; which means it must lie along the radius of the circle. We can conclude, then, that there is a force acting on the object, and that this force is directed along the radius of the circle. You'll learn more about such forces in lesson 13.

Lecture 12

In today's film, Dr. Purcell showed you that for a given force, acceleration is inversely proportional to inertial mass. That is:

$$a \propto \frac{1}{m}$$

Last time you were here, you saw that:

$$a \propto F$$

If we put these together, we get

$$a \propto (F) \times (\frac{1}{m})$$

or $$a \propto \frac{F}{m}$$

The same relationships can be expressed as $F \propto ma$.

In order to be able to work more easily with this important relationship, we'd like to replace the proportionality sign by an equal sign. In order to accomplish this, we define a unit of force which has units of mass times acceleration.

Thus we can say now that F = ma.

Our unit of force is called the newton and we want it to be consistent with the units of the MKS system in which mass is measured in kilograms and velocity in meters per second. Now, acceleration is simply the rate of change of velocity, or the change in velocity per unit time; thus you can see that it has units of meters per second per second, or meters per second squared. Stop and think this over for a moment if it isn't yet obvious to you.

So, in order to have our basic unit of force in terms of the basic units of the MKS system, we define the newton as:

1 newton = 1 kilogram-meter per second per second.

That is, a force of one newton will give an acceleration of one meter per second squared to a mass of one kilogram. This definition of a newton you will need to know in order to work problems. Now that we've defined our unit of force, we'll continue with a discussion of a very particular kind of force. This force is weight which is simply the gravitational force acting on an object of mass m. Now you're already familiar with the concept of weight (although you may never have thought of it as a force) and you will not be at all surprised at the results of the following experiment. If we take two standard masses, say 1 kilogram and 2 kilograms, and measure their weight at different points on the earth, we will find that the 2 kilogram mass always has twice the weight that the 1 kilogram mass has. This is not quite as trivial as it may sound because the weight of a given mass will vary slightly from one point on the earth to another--we'll hear more about this later. But the ratio of the two weights is always 2 to 1. Another way of expressing this is to say that the weight W is proportional to the mass m. Back in lesson 3 we learned that such a proportionality can be written in the more useful form of the equality:

$W = m\,g$, where g is a proportionality factor.

Now we know that weight is a force, the force of gravitational pull on m, and that g must therefore have the units of acceleration. (Remember you just checked that out a couple of minutes ago and found that 1 kilogram times 1 meter per second per second = 1 kilogram-meter per second per second, which is called 1 newton. of force.)

The proportionality constant g is called the acceleration of gravity, or the gravitational acceleration. It has been carefully measured and if we tell you the value of g, you can calculate the weight, W, of a known mass m by the simple relationship, $W = mg$. Notice that weight is a force; like all forces, it has a direction as well as a magnitude. The direction, of course, is straight down toward the center of the earth. Mass, unlike weight, is a scalar quantity. It does not have a direction.

Now, the value of weight depends upon where it is measured in space because the value of g (that is, gravitational acceleration) depends upon the distance of separation of the objects as well as their masses. That is, the closer the earth and another object are to each other, the stronger the gravitational attraction between them. For objects on the surface of the earth, the separation distance is considered to be the distance between the object and the center of the earth.

This is consistent with the results of Dr. Purcell's demonstration in the movie in which he showed that objects of equal mass have equal weight if measured at the same location. However, it also follows that two objects having the same mass will have quite different weights if one measurement is taken on Mt. Everest and the other in a deep underground mine, or even if the two measurements are done at the equator and the North Pole. This last statement is true since the earth is not exactly spherical and the distance from the center of the earth to the surface is different at the poles from what it is at the equator. As a result, the value of g varies slightly as you move from pole to equator. Now (we hope!) you may begin to appreciate the difference between mass and weight which was briefly alluded to in lesson 5.

Now consider an object falling toward the earth. It has two forces acting on it; weight, directed downward, and an air resistance which can be considered as a vector pointing straight up.

F_{air} increases as the velocity increases and if the object is allowed to fall long enough, F_{air} will eventually be equal in magnitude to W.

This balancing of forces is what keeps raindrops from killing people. If there were no air resistance, the raindrops would accelerate to very high speeds and become pretty deadly.

In talking of a falling body, we can see that the net force producing the object's acceleration is:

$$F_{net} = W - F_{air}$$

or, substituting symbols:

$$ma = mg - F_{air}$$

and the resulting acceleration is:

$$a = \frac{mg - F_{air}}{m}$$

These equations are given in your supplement. Turn to them now if you haven't already.

If we were able to reduce F_{air} to zero by allowing the object to fall in a vacuum, we would have:

$$a = \frac{mg - 0}{m}$$

$$a = \frac{mg}{m}$$

$$a = g$$

Look at this result. What it tells us is that all masses experience the same acceleration in the vicinity of the earth,--or would, if it were not for air resistance. Even with air resistance present, this result is pretty close for all but objects with a large ratio of surface area to mass--such as ping pong balls, or feathers. There's a story that long ago the famous scientist Galileo demonstrated this effect by dropping various pairs of masses off of the leaning tower of Pisa. The story is probably not true but if he had done so observers on the ground would have seen that the large and small objects struck the ground at very nearly the same time. If you don't believe this, why not go to some high vantage point such as the stairwell of your dorm and experiment with tennis balls, softballs, basketballs, etc. Don't use ping pong balls. They're light enough to be affected by air resistance. And be careful not to hit anybody on the head.

The constant nature of gravitational acceleration for all masses can be demonstrated even more dramatically by means of an experiment we unfortunately can't show here. If we place a feather and a block of wood in a long glass cylinder which has been evacuated (that is, has had all the air pumped out of it), and we release them from the top of the cylinder at the same time, they would hit the bottom at the same time. We can do this for any object and we find that g is constant for all objects if we measure it at the same place.

Near the surface of the earth, the average value of g is 9.8 m/sec^2. This value changes slightly from place to place, but 9.8 m/sec^2 is close enough for our use. You'll need to remember the value for g because we will be using it extensively later on. Here it is again: $g = 9.8$ meters per second per second.

Now you know how to find the weight of an object from its mass or, conversely, its mass from its weight (assuming of course that we are on the surface of the earth). You can do this by solving:

$$W = mg$$

for the appropriate value. You will be doing this shortly on the terminal.

We said that weight was a force. If that is true, weight and force must have equivalent units. You know from the last lesson that force is measured in newtons and

$$1 \text{ newton} = 1 \text{ kg m/sec}^2$$

Let's see if weight is equivalent.

$$W = mg$$

$$W = (\text{kg})(\text{m/sec}^2) = \text{newton}$$

Well, so much for that. Both weight and force are measured in newtons. When we talk of an object's weight, we're speaking in terms of newtons. If we're talking of mass, we measure it in kilograms. This distinction between weight and mass is an important one. Remember weight is a force; mass is not.

Figure out your weight in newtons and the next time someone asks you how much you weigh, you can confuse them with a scientific answer.

Well, that's all we're going to cover in this lesson. Now report to your terminal for a review quiz.

Lecture 13a - Deflecting Forces

In lesson 10, you were introduced to the concept of force. You studied Newton's second law and learned that a force, when applied to a mass, produces a change in the velocity with which the mass is moving. The rate of change of velocity is called acceleration. If the object started at rest, the force sets it in motion and gives it an acceleration. All this was summed up in the neat equation:

$$F = ma.$$

This equation applies to the motion of bodies throughout the universe. You might be tempted to think, therefore, that all motion would be very simple to analyze. But be careful! There is a catch. In all the situations you have looked at so far, the acceleration has taken place in the direction of the applied force. Let's take a look at a simple example. A 10 kg. toy wagon is blocking Professor Smith's driveway. When he gets home tired after a hard day's work teaching physics 107 to the other section and sees the wagon there, he flies into a rage. He jumps out of his car, runs up to the wagon, and pushes it with a force of 20 newtons, thereby imparting to it an acceleration of 2 m/sec^2 . This was an easy problem, since we can assume that the wagon moves away in a straight line in precisely the direction in which he pushed it. It started out with zero velocity, then gained greater and greater velocity during the time he pushed it. In this case, the magnitude of the velocity is changing but the direction stays the same. This means that the acceleration vector has the same direction as the velocity, as you'll see in the following example: Suppose Professor Smith pushed the wagon in a northerly direction toward his neighbor's yard. After one second the wagon would have a velocity of 2 m/sec north. After two seconds, the velocity would be 4 m/sec north. As long as the acceleration is in the same direction as the velocity at each moment, the direction of motion stays the same, and our wagon follows a straight-line course. Conversely, if an object follows a straight-line path, but with increasing speed, we can conclude that the acceleration vector is in the same direction as the velocity vector at each moment.

Well, you may say that's pretty easy. And it is--so far. But, don't forget. There is another kind of motion: motion in a curved path.

Most of us have at least some familiarity with motion in a curved path. Living in Florida in the space age, it's almost impossible not to know that there are man-made satellites which orbit about the earth in nearly circular paths, just as the planets move about the sun. There are other familiar examples, too. An object thrown into the air follows a parabolic course--as anyone who has ever played baseball or football realizes.

Let's think about acceleration again for a moment. We define acceleration as the time rate of change of velocity. But velocity is a vector quantity, and that means that it can change in both magnitude and direction. When we talked about straight-line motion and used the equation F = ma, the change in velocity referred to by the symbol "a" was a change of magnitude, or speed, only since there was no change in direction. However, we could easily find a situation in which a change in both speed and direction are involved. And under certain conditions we could even have a continuous change in direction only, with the speed remaining constant.

Let us examine this last situation. Imagine that we push steadily with a constant force on a body, always pulling or pushing at right angles to the direction of its motion. Such a situation is demonstrated in the film by means of a dry ice puck on a string. The kind of force involved in such a situation is called a pure deflecting force.

At this point, you will benefit by seeing an excellent film on the subject of deflecting forces which will clarify some of the points we've already mentioned, and introduce some new ones. A deflecting force is defined as the component of force perpendicular to the instantaneous velocity, and you'll see more clearly what we mean by that. Be sure to note the difference between a deflecting force and its special case, the pure deflecting force. In this latter case, the net force is at right angles to the motion. Pure deflecting forces are associated with motion in a uniformly curved path; such a path, as you may already have guessed, turns out to be none other than a circle.

To examine the applicability of Newton's law to the case of deflecting forces, an expression for the acceleration is derived, and the direction of $\vec{v}$ and $\vec{a}$ are established relative to a rotating vector, $\vec{R}$. Be sure to follow this part carefully. Now, go and ask the proctor for film #305, "Deflecting Forces." When you have seen it, please go to your terminal for a review on the film.

After the film, this lecture will be continued on another tape.

Lecture 13b - Deflecting Forces

The film with its photographs of the dry ice puck attached to a string has probably clarified for you what is meant by a deflecting force. Let's use our wagon situation to illustrate deflecting forces in a different way. Imagine that the wagon which is blocking Professor Smith's driveway is attached to a long rope and that the owner--a very strong little boy--is holding onto the other end. Imagine also that he has a very special kind of driveway, a frictionless one. The professor kicks the wagon (stubbing his toe) and it is set in motion. Since the force was only instantaneously applied, the wagon does not continue to accelerate, but moves with a constant velocity. Now the boy holding onto it gives it a small tug in a direction perpendicular to the direction in which the wagon is moving. It changes its course. But now he exerts a force perpendicular to the new direction and at every instant thereafter he exerts a force perpendicular to the direction of motion of the wagon at that instant. What this amounts to then is that he is swinging the wagon around and around the driveway in a circle of which he is the center (this is one awfully big driveway). We now have a good example of circular motion. Notice that no force is necessary to keep the wagon moving; its inertia takes care of that. If the wagon were not constrained by the rope, it would still be moving, only it would be moving in a straight line. The perpendicular force which the boy exerts on it is responsible for the change in direction only. This is the only effect it has. It is very important to see this.

Now, if we're exerting a force which is always at right angles to the direction of motion, there is no component of force in the direction of motion. Therefore, there is no acceleration along the path and the speed of the body stays constant while the direction of motion changes continuously. After the lecture, take a look at the diagrams in your supplement and read the explanations carefully. By the time you are finished, you will probably have a much better understanding of the process of circular motion.

Here is an obviously more complicated situation than those we have encountered before, yet, according to Newton's law, we must still have $\vec{F} = m\vec{a}$. And how can we work this? Well, since the direction of the velocity is changing uniformly per unit time, we still have a change in velocity per unit time and our condition is satisfied. We have been in the habit of thinking of acceleration in terms of change of speed; it's very important at this point that we get used to the idea of acceleration also as a change in direction.

Now, let's find out more about the magnitude of this acceleration. Say the radius of the circle in which the body moves is R. In one revolution, the body travels a distance of $2\pi R$. If the period (which is the time in which one revolution is accomplished) is called T, then the speed is

$$V = \frac{2\pi R}{T} .$$

The time T for one revolution is called the period. This situation is described in Figure 1 of your supplement. We may think of the position vector as rotating uniformly around the circle. Since the velocity at each moment is in the direction of the tangent to the path at that point, the velocity vector, n, is always perpendicular to the position vector, R .

Just as the position vector rotates uniformly about the circle so does the velocity vector, which is perpendicular to it. This is a little more difficult to see at first. But remember that we can move a vector if we preserve its direction. If we shift the velocity vector, v, in Figure 1 and place it at the center of a circle, as in Figure 2, it too must rotate uniformly through a complete circle during each period T. The period T for the velocity vector is the same as for the position vector.

From the diagram and geometrical considerations, you can see the circumference of the circle is $2\pi v$, and the acceleration which is simply the time rate of change of velocity must equal this circumference divided by the period, T. Thus, acceleration is $a = \frac{2\pi v}{T}$.

We can now combine these last two equations to get $a = \frac{v^2}{R}$, or $a = \frac{4\pi^2 R}{T^2}$ as the value of our acceleration. This acceleration associated with circular motion is called centripetal acceleration because it is always directed toward the center of the circle and centripetal means "center-seeking."

Now we can apply our familiar equation, $F = ma$. For the force producing centripetal acceleration we use our two previously derived formulas:

$$F = \frac{4m\pi^2 R}{T^2} \qquad \text{or} \qquad F = \frac{mv^2}{R}$$

This centripetal force is directed toward the center of the circle also.

The relationships we've developed in this lesson are extremely useful in the study of astronomical bodies and earth satellites. We'll say something about these in our next lesson.

Now, please go back to your terminal for a short review. This concludes lecture 13.

Lesson 14 - Planets and Satellites

In today's lecture, we're going to pick up where we left off last time and show you how some of the things you learned then can be applied to the study of planets and satellites. This, of course, is a topic of particular interest here in Florida where we have such an active space program. Although today it's the man-made satellites which are the center of the most interest, they could not have been put into orbit without scientists having first attained a thorough understanding of the motions of the moon and planets. Man-made satellites orbit the earth in the same way that the moon does. The moon's motion, in turn, is analogous to the revolutions of the planets around the sun. All of these natural bodies follow elliptical orbits of very small eccentricity; which means that they are very nearly circular. So do most artificial satellites, except for certain cases in which it is, for some reason or another, desirable to have an orbit of high eccentricity. The general procedure in launching a man-made satellite is to use a multi-stage rocket. For example, one rocket may carry the satellite and another rocket to the top of the earth's atmosphere. There the second rocket takes over, firing the satellite nearly horizontally in surroundings where there is very little air resistance to impede the satellite's motion in its nearly-circular orbit. This, of course, is a great oversimplification.

Although the analysis of elliptical orbits is beyond the scope of this course, we can deal easily enough with circular orbits. The orbits of the planets and of many satellites are nearly enough circular that treating them as though they were indeed circular will introduce relatively little error.

As we mentioned earlier, it was through observations of the solar system that man was originally able to accumulate the knowledge that made the later spectacular technological developments possible. In the seventeenth century, Newton watched the planets moving about the sun in such a way that both their speed and direction were continuously changing. This means acceleration, and according to Newton's law, a force is always required to produce an acceleration. Since there was no way for him to measure the force between the sun and a planet directly, he was obliged to guess at its nature, and then see whether his hypothetical force would be successful in predicting the motions of planets in the future. He postulated that

$$F = \frac{Gm_1m_2}{r^2}$$

Where F is the gravitational force between any two objects, m_1 and m_2 are the masses of the objects, r the distance between their centers of mass, and G is a proportionality constant which Newton called the universal gravitational constant. In the case of the nearly spherical planets, r would be the distance between their centers.

It was found that this relationship predicted the motions of the planets with great success. The fact that it worked suggested, but did not prove conclusively, that the equation was correct. However, Cavendish later gathered some very persuasive experimental evidence to suggest that Newton's hypothesis was indeed a law. In a very ingenious and delicate experiment, he actually managed to directly observe the effects of gravitational attraction between a pair of masses. Then he proceeded to measure the value of the gravitational constant, G.

You saw that experiment recreated in the film "Forces" a few lessons ago, and it's also briefly mentioned in your text.

Now that we have Newton's law of gravitation, we can go ahead and describe the motions of a satellite. We won't use the exact development given in your text, but instead will draw upon what you learned in the previous lesson.

Remember that in order for an object to move in a circular orbit there must be a force corresponding to the acceleration which causes the object to move in a circular path; this acceleration we called the centripetal, or center-seeking acceleration. Its magnitude, a, is given by:

$$a = \frac{v^2}{r},$$

where v is the speed of the body and r is the radius of its orbit. (This is Equation 1 in your supplement.)

Let's apply these results to the motion of a satellite around the earth. Assuming a circular path, the force supplying the centripetal acceleration must be equal to

$$ma = \frac{mv^2}{r}$$ (This is Equation 2 in your supplement.)

This tells us how large a force is required; but what is the force which supplies this acceleration? It is the gravitational attraction of the earth on the satellite. You could calculate this force from Newton's law of gravitational attraction if you knew the masses of the earth and the satellite, and the radius of the orbit. But we're going to simplify our approach by assuming we know the gravitational acceleration, small g, at a distance r from the center of the earth. Then the gravitational attraction between earth and satellite is simply F = mg, where m is the mass of the satellite, as shown in Equation 3.

Since this is the force which supplies the centripetal acceleration v^2/r to the mass m, it follows from F = ma that

$$mg = \frac{mv^2}{r}.$$

(This is Equation 4.)

Dividing both sides of the equation by small m gives us Equation 5:

$$g = \frac{v^2}{r}$$

Another way of writing this is (Equation 6):

$$v^2 = gr$$

Notice what this equation tells you. If an earth's satellite is moving in a circular orbit of radius r, you can calculate the speed of that satellite, and its mass doesn't come into the calculation at all. In other words, the speed of the satellite is independent of its mass, and depends only on the radius r and the gravitational acceleration at that point, small g. Notice though that this g is not equal to 9.8 m/sec^2 as it is in problems about bodies near the earth's surface, because the value of g gets smaller as you get farther from the center of the earth. So for a satellite, small g will be smaller than 9.8 m/sec^2 . Here's an example of using Equation 6 to calculate the speed of the satellite. A satellite moves in an orbit 400 km above the surface of the earth. The radius of the orbit, then , is equal to the radius of the earth plus 400 km, or

$$\begin{aligned} r &= 400 \text{ km} + r(\text{earth}) \\ &= .400 \times 10^6 \text{ m} + r(\text{earth}) \\ &= 6.8 \times 10^6 \text{ meters,} \end{aligned}$$

small g has been measured at that r to be 8.6 m/sec^2 ,

$$\text{so } v = \sqrt{gr}$$

$$= \sqrt{(8.6)\ (6.8)\ (10^6)\ \frac{m^2}{sec^2}} = 7.6 \times 10^3 \text{ m/sec}$$

Knowing the speed and radius, you can also figure the period T of the motion, and this tells you how often the satellite will pass a given point, so that a table of times when the satellite will be visible can be made up.

$$2 \pi r = v T$$

$$T = \frac{2 \pi r}{v} = \frac{(2 \pi)\ (6.8 \times 10^6 \text{ m})}{7.6 \times 10^3 \text{ m/sec}} = 5.6 \times 10^3 \text{ sec} = 93 \text{ min.}$$

Similar considerations apply to the motion of the moon about the earth, and to the motion of the planets about the sun, with the sun as the center of the planets' orbits.

Observing the other planets from earth, they do not appear to have the simple, most circular orbits described by Newton's law. To explain their motion relative to the earth, it is necessary to take into account some strange forces and accelerations; but viewed from the sun, the simple centripetal force of Newton's law completely describes them. In other words, it is simpler to describe the motion of the planets from the point of view of an observer at the sun than one at the earth. What we observe about the motion of an object depends on our state of motion relative to that object. This idea is presented very convincingly in the movie "Frames of Reference." Please go to your terminal now for a quiz on this lecture 14, then ask the proctor for Film No. 307, "Frames of Reference."

This concludes lecture 14.

Lesson 15 - Momentum

Today we're going to talk about momentum and the related topic of impulse. The chances are you already have a fairly good feeling for what momentum is even if you have never actually thought about it. For example, if someone shouted to you to stop a tennis ball which was rolling down a hill you would have no qualms, whereas, if the runaway object was a car whose brakes had failed, you might have some second thoughts about stepping into its path. Your apprehension in this second case stems from the fact that even if the two objects are moving with equal velocities, the car has far more momentum than the ball and this is due to its greater mass. If you stepped in front of the car and tried to stop it, you would soon acquire a good deal of momentum yourself as you went careening off into the air! I'm sure that idea doesn't appeal to you, so you just let the car go by until it smashes into something at the bottom of the hill. The extent of the damage suggests to you that a rather large force must have been at work here. This kind of force, which is associated with the impact, is called an impulsive force.

Let us go back for a moment to the familiar equation:

$$F = ma$$

We know that acceleration is merely $\frac{\Delta v}{\Delta T}$. Therefore, this equation can be rewritten as :

$$F = \frac{m\Delta v}{\Delta t} .$$

If we multiply both sides by Δt, it takes on the form $F\Delta t = m\Delta v$. Although this equation is simply another expression of the old one, it is cast in such a way that it can give us additional information. Let's take a look at the left side first. The quantity $F \Delta t$ is called the impulse, and it is a very interesting quantity. We usually use an impulse equation in situations where a force of a quite variable and somewhat erratic nature is applied for a very short time -- often only a small fraction of a second. For example, the force with which a baseball bat strikes the ball is an impulsive force. It would be very difficult to determine the force at each instant. Notice that the quantity impulse has the dimensions of force multiplied by time. Δt is of course the time during which the force is applied. It is also implied that F is the average force during the time Δt.

Now take a look at the other side of the equation. Something is changing over here, too--namely, the velocity. If we had a special name for the quantity mv, we could say also that this was changing. And we do--we call mv the momentum. We thus say that the change in momentum of an object is equal to the magnitude of the impulse applied to it. It's interesting to note that this is the form in which Newton originally expressed his law; he didn't say F = ma. He referred to mv as the "quantity of motion."

Now you may ask: what are the uses of this new quantity momentum? Well, it is used to describe the motion of a particle, just as velocity is and, as we shall shortly see. It is sometimes even handier for this purpose than the velocity.

Let us see why this is so. Imagine a particle moving along, with a constant velocity, and say you want to describe its motion. Your first thought is to give its velocity. When you know that, you can predict its position at any future time; that is to say, you have a complete description of its motion. But now, let us say that it undergoes a head-on elastic collision with another particle. We will take an elastic collision to be one in which neither particle is bent or broken or deformed in any way and therefore, kinetic energy is conserved. Let's say, just to make things easy to visualize, that our particles are two billiard balls of different masses m_1 and m_2, and that they are traveling toward each other at differing velocities, v_1 and v_2, along a frictionless surface. They collide, spend a very brief moment in contact with each other and then rebound. During their brief moment of contact, they exert equal impulsive forces $F \Delta t$ on each other. Therefore, they must be pushing on each other equally hard.

Although this situation lasts for only a very brief time, we can apply our impulse equation: $F \Delta t = m \Delta v$ and $\Delta v_1 = \frac{F \Delta t}{m_1}$, $\Delta v_2 = \frac{F \Delta t}{m_2}$.

Since $F \Delta t$ is the same for both, it's easy to see that if the masses differ, the changes in velocity of the two balls differ from each other. So we can see that at least where collisions are involved, the velocity alone is not the best way of describing a particle's motion.

What about impulse, you may say: We have seen that impulse is indeed the same for both balls. But impulse is difficult to measure. If we see a billiard ball rolling along, we have no way of knowing what impulse got it started. So, impulse is not an ideal way to describe a particle's motion. This gives us an idea, however. Why not use the other side of the impulse equation $m \Delta v$. Since mv is momentum, the quantity $m \Delta v$ would be equal to $\Delta (mv)$, the change in momentum occurring during a collision. This, it turns out, is the answer to our problem, for momentum is easily measurable. We know this from experiments; if we measure the momenta of two bodies both before and after the collision, we always find that the momentum lost by one body is exactly equal to that gained by the other. This is true since $F_1 \Delta t = -F_2 \Delta t$ and, therefore $\Delta (mv)_1 = - \Delta (m v)_2$. Your supplement outlines the equations just given as well as what follows.

It can be stated algebraically as follows: If m_1 has velocity v_1 before collision and v_1' after collision, and if m_2 has velocity v_2 before collision and v_2' after collision, then :

$$m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2'.$$

Momentum is frequently designated by the symbol P. If P is the total momentum of the system before collision and P' the total momentum after collision, then we say :

$$P' = P \text{ or } \quad P = 0.$$

That is, during the collision process, there is no change in momentum.

Therefore, momentum is conserved. This is true whether or not kinetic energy is conserved and whether or not the collision is head-on. This fact places the momentum conservation law on an equal basis with the generalized law of conservation of energy.

This concludes lecture 15. Look at the short film FSU#38 "Conservation of Momentum--Rocket" before returning to your terminal.

Lecture 16 - Work and Kinetic Energy

I. Work as a Measure of Energy Transfer

Today we are going to learn about work and energy. Although you probably already have some idea of what work and energy are, in physics we must define these concepts carefully. Let's start with work.

If you push against a brick wall, nothing happens. If someone else observes the wall after you have pushed on it, he cannot find out how hard you pushed or for how long; in fact, he could not even determine that you had exerted any force at all on the wall unless he made some very precise measurements. (If you do manage to push over the wall, call Bill Peterson. He will want to know. Barring this uncommon turn of events, let us continue.)

If you exert a force on a baseball for a short length of time in the act of throwing it, the outside observer could easily detect changes in the system by measuring the velocity of the ball at the instant it left the hand. This could be done by measuring the displacement of the baseball. The essential difference in the two examples is that a change in motion is produced in this second case, whereas no observable effect is produced when a force is exerted against the brick wall.

When you exerted a force on the baseball, you transferred energy to it. In the case of the brick wall, on the other hand, no energy was transferred, assuming you didn't crush it or leave it changed in some way.

In this study, we will use work as a precise measure of energy transfer.

And just how do we go about applying this measure? We must find some combination of the physical quantities that we can measure to tell us how much energy is transferred. It seems clear that the size of the force is involved, as is also the distance the object moves while that force is acting upon it. We will use as our definition of work the following: the component of the applied force along the direction of motion times the distance moved. This can be written as:

Equation 1. $W = (F_x)\ (x)$

where x is the distance moved and F_x is the component of force in the x direction.

Now why are we being so careful about saying the component of force in the direction of motion? Let us consider an example in which there is motion but still no work done by the applied force. If a flatcar is coasting along frictionless tracks at constant speed and a force is applied perpendicular to the direction of motion, nothing happens. That is, the speed of the flatcar remains constant. An observer of the motion of the flatcar could not discern the effect of the applied force. We say then that no work has been done by the applied force. If, however, the applied force has a component in the direction of motion of the flatcar, then the speed of the flatcar will increase and work will have been performed. But if the single force applied to a body is always at right angles to the velocity, that force does no work. What does this tell you about centripetal force in uniform circular motion--does it do work?

Again, work is equal to the component of applied force along the direction of displacement of the object, times the distance through which this object moves.

In many cases, force and displacement will be in the same direction so we can use the equation: $W = F \times d$. This is shown on page 47 in Van Name.

II. Energy of Motion

We have implied that the result of work performed on a body is a change in the position of the body or a change in its velocity. Let us first take up the latter and by the use of Newton's Second Law actually calculate the change in velocity of an object when a constant net external force is applied. You can follow this argument in your supplement, equations 2 through 8. Let the object be a baseball with mass m and initial velocity, $v_1 = 0$. If a constant force, F, is applied for a time, t, the ball is accelerated according to Newton's Second Law: Force equals mass times acceleration.

Equation 2. $F = ma$

If the ball moves through a distance, d, while the force is applied, then the amount of work done by the force is:

Equation 3 $W = Fd = mad.$

The distance, d, through which the force acts is given by the average velocity, $\bar{v}$, multiplied by the time during which the force is applied:

Equation 4 $d = \bar{v}\, t = \frac{(v_1 + v)}{2} t$, where v is the final velocity.

This is simply because the average of two numbers is found by adding them together and then dividing by 2. The acceleration is equal to the change in velocity per unit time.

Equation 5 $a = \frac{v - v_1}{t}$

Since we have chosen a case in which the initial velocity v_1 is equal to zero we have:

Equation 6 $d = 1/2\ vt$ and $a = \frac{v}{t}$

Therefore, the work done by the applied force is:

Equation 7 $W = mad = m \times \frac{v}{t} \times 1/2\ vt = 1/2\ m(v)^2$, equals

1/2 the mass of the object times the square of its final velocity.

This result, $1/2\ mv^2$, is called the kinetic energy of the body which simply means energy of motion. Kinetic energy abbreviated as K.E. is therefore given by the equation:

Equation 8 $$K.E. = 1/2\ mv^2$$

Thus we have performed work on the body and given it kinetic energy. Notice that this energy is independent of how the body got moving. It is a function only of the body's mass and present speed.

The unit for kinetic energy must be equivalent to the units for work. The mks unit for work is the product of the units for force and distance, i.e., (newton)(meter). It is conventional to define an equivalent unit, the joule, as the unit of energy.

Equation 9 $$1 \text{ joule} = 1 \text{ newton-meter} = 1 \text{ Kg } m^2/sec^2$$

Notice that work, like energy, is a scalar quantity, not a vector quantity. It does not have a direction, only a magnitude.

III. Elastic Collisions.

With this definition of kinetic energy in mind, let us consider a collision problem in which we know the masses and velocities of the two bodies before the collision and want to find their velocities after collision. When two bodies free from all external forces collide the total momentum is conserved. As a review of momentum conservation, we know this because Newton's Second Law can be expressed as force equals change in momentum divided by the time interval over which that change occurs. If the two bodies are free of external forces then the total momentum change of the two particles taken together must be zero. We have written this conservation of momentum equation in your supplement as:

Equation 10 $$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$$

where m_1 and m_2 are the masses of the two bodies; v_1 and v_2 are the velocities before collision, and v_1' and v_2' are the velocities after collision. The left hand side of the equation is then the total momentum of both particles before collision, and the right hand side is the total momentum after the collision. Remember that momentum is a vector.

An elastic collision is defined as one in which the kinetic energy is conserved. This is written in your supplement as:

Equation 11 $$1/2\ m_1v_1^2 + 1/2\ m_2v_2^2 = 1/2\ m_1v_1'^2 + 1/2\ m_2v_2'^2$$

That is, we equate the sum of the kinetic energies for particles 1 and 2 before collision to a sum of the kinetic energies after collision. The total kinetic energy of the system remains constant, this is what we mean by an elastic collision. Of course the kinetic energy of each body may change. But any kinetic energy lost by one must be gained by the other. Now the energy equation along with the momentum equation gives us two simultaneous equations for the unknowns v_1' and v_2'. The algebra for solving them is of no interest to the discussion. If you wish you can do it yourself. As a special case, let's consider the problem of one billiard ball (m_1) hitting another one (m_2) which is initially at rest, i.e., $v_2 = 0$. We want v_1' and v_2', the velocities of the two balls after collision. The solutions are given as:

Equation 12 $$v_1' = \frac{m_1-m_2}{m_1+m_2} \times v_1$$

Equation 13 $$v_2' = \frac{2m_1}{m_1+m_2} \times v_1$$

There is a demonstration film loop for this case in which the two bodies have equal mass, so that $m_1 = m_2 = m$. In that case:

Equation 14 $$v_1' = \frac{m-m}{m+m} \quad v_1 = 0$$

Equation 15 $$v_2' = \frac{2m}{m+m} \times v_1 = v_1$$

In film loop #80-277, you will see that if two objects of equal mass collide, and one of them was at rest, the one at rest will move off with the same velocity as the originally moving object and the originally moving object will be at rest aftet the collision.

That's a very critical experiment. If it works, we've shown a lot of physics to be correct. We used kinetic energy, work, impulse, momentum, and Newton's law of motion to predict the behavior of these objects in this simple experiment. You can also see this experiment in film loop FSU-31. Both loops demonstrate conservation of momentum. The FSU film uses billiard balls; the other one uses a different apparatus, but the principle involved is the same.

There are a number of interesting demonstrations on each loop, including the one we've been discussing: an elastic collision between a moving body and one that is originally at rest. Let's see if our prediction of final velocities is correct.

Now please ask the proctor for film loop FSU-31 or 80-277, entitled "Conservation of Momentum." After viewing one or both of these, please return to your terminal for a review.

The next time you come, we'll talk about another kind of energy called potential energy and the principle of conservation of total mechanical energy.

Lecture 17 - Potential Energy

In the last lesson we discussed the effect of a single force acting on a body and found that the work done on the body was given by the change in kinetic energy of the body or, in the case of the body being initially at rest, $W = 1/2mv^2$. We will now consider an example in which more than one force might act on the body, but we will calculate the work done by only one specific force. This will lead us to the concept of potential energy.

Suppose an object is lifted up to a height, h, above the floor. Although other forces might be acting on the object, the particular force of interest now is the force of gravity--which is a downward force equal to the weight (mg) of the object. The object moved a distance, h, so according to our definition, the amount of work done against this force of gravity is $W = mgh$.

At its new position, h, above the starting point, the object has the potential of moving. We say that work which has been performed has gone into giving the body an energy due to its new position. The energy is stored and can be recovered by allowing the object to fall. In such a case, we say that object has gained gravitational potential energy (P.E.) which is equal to the amount of work done by the applied force against the force of gravity. If the object is allowed to fall, the potential energy decreases as h decreases, and the kinetic energy increases as the gravitational force accelerates the object. The work done by the gravitational force while the object is falling a distance, h, is $W_{(fall)} = mgh$. Since the gravitational force is the only force acting, during the fall the work is also equal to the increase in kinetic energy, $W_{(fall)} = 1/2mv^2$, where v is the final velocity at the end of the fall. Rewriting this, the work done by the gravitational force during the fall by $W_{(fall)} = mgh = 1/2mv^2$ (Eq. 1). But mgh is the initial value for potential energy at a height, h, before the start of the fall. Therefore:

Equation 2 $\qquad (P.E.)_{initial} = (KE)_{final}$

We see that by introducing the concept of potential energy, the problem of a falling body can be thought of as the conversion of potential energy into kinetic energy. However, as will be pointed out now, the total energy of the body stays the same at each point along the fall.

Notice that in this case, the initial kinetic energy is zero and the final potential energy is also zero.

We can also write a more general equation for energy conservation:

Equation 3 $\qquad (PE)_{initial} + (KE)_{initial} = (PE)_{final} + (KE)_{final}$

This equation is true for any value of the height and any value of initial velocity. That is, the sum of potential energy and kinetic energy at any value of h is the same as for any other value.

Another way of saying this is to say that potential energy plus kinetic energy is a constant or that it is conserved. This sum, PE + KE, is called the total mechanical energy of the body, and the equation: PE + KE = constant, is called the law of conservation of total mechanical energy.

Conservation of total mechanical energy can be used in the following way to find the final velocity of the object after falling a distance, h, assuming the object had zero initial velocity.

Equation 4 $$(PE)_{initial} + (KE)_{initial} = (PE)_{final} + (KE)_{final}$$

$$mgh + 0 = 0 + 1/2 \quad v^2$$

$$gh = 1/2 \quad v^2$$

$$v^2 = 2gh$$

and $$v = 2gh$$

Now, knowing the acceleration due to gravity ($g = 9.8\ m/sec^2$), one can easily calculate the velocity for any height of fall, h. If, for example, h = 10 meters, then $v = \sqrt{2 \times 9.8\ m/sec^2 \times 10\ m}$

$$= \sqrt{196 \frac{m^2}{sec^2}} = 14\ m/sec$$

Actually, this is the same calculation that would be required if we started from Newton's second law directly. The energy concept is an alternate way of considering such problems--and it is simpler in some cases.

It is important to notice that we have developed the concepts of potential energy and conservation of mechanical energy by investigating the effects of doing work against a gravitation force. Here the potential energy, mgh, is called a gravitational potential energy. There are other types of potential energy, for example, the energy stored in a compressed spring or in a storage battery. We will consider some of these other kinds of potential energy in later lessons.

This concludes Lecture 17 on Potential Energy.

Lecture 19 - Introduction to Electrical Forces

The purpose of today's lesson is to introduce you to the subject of electricity and, specifically, electrical forces. In a few minutes, we'll show you a film about these forces. But before you can really understand them, you should have a bit of appreciation for what electricity actually is.

Let's turn first to what you already know from previous experience. Nearly everyone at some time or another has had the experience of getting a shock from the handle of a car door on a dry day. And you have probably also now and then noticed a crackling sound while you were combing your hair with a rubber comb. If you happen to touch this same comb to some tiny pieces of paper or lint just after using it, it will pick them up.

These two instances are both examples of electrical phenomena. The one with the rubber comb is a bit easier to explain at this point, and it can be further simplified. Let us say that instead of a comb we have a hard rubber rod, and that instead of combing our hair with it, we rub it with a piece of fur. Or--let's be really extravagant and say we have two such rods and have rubbed each of them vigorously against the collar of a new $2500 mink coat. We now let one dangle from a piece of string and bring the other one toward it--and we find that the dangling one tries to move away. In other words, there seems to be some sort of a force of repulsion between them. A similar state of affairs exists between a pair of glass rods which have been rubbed with silk: they, too, repel each other. On the other hand, a rubber rod which has been rubbed with fur and a glass rod which has been rubbed with silk will attract each other.

It would seem as if something has been rubbed off onto the two rods from the two pieces of material, and it would also seem that this something --whatever it is--comes in two different kinds. Since we can't just go around calling it "this something," we give it a more scientific-sounding name; we call it "electric charge." Furthermore, we adopt the convention of calling the charge which appears on the glass rod positive (or +) and that which appears on the rubber rod negative (or -).

It turns out that this electric charge comes in very tiny fundamental units, all of the same size. You'll learn more about them in later lessons. But we aren't particularly concerned with the nature of the fundamental units just now--what we are interested in right now are the forces which exist between charged bodies, regardless of how much charge they happen to be carrying.

The movie you are about to see will tell you more about this. In 1787, a Frenchman named Coulomb formulated the law of electrical forces which bears his name. He said that the force between two charged bodies was:

$$F = \frac{K Q_1 Q_2}{R^2}$$

where Q_1 was the total charge on the first body, Q_2 the total charge on the second body, R, the distance between them, and K an experimentally determined constant. He asserted, furthermore, that this force was attractive if the bodies were oppositely charged, and repulsive if they were similarly charged. Notice that this law is analogous to Newton's gravitational law. There is one big difference, however. Whereas electrical force can be either attractive or repulsive, the gravitational force is always attractive.

In today's film you will be shown an experimental verification of Coulomb's law; through experiments conducted with a pair of charged metallic spheres, you will see that the Coulomb force between two charged bodies does indeed vary directly as the magnitudes of their charges and inversely as the square of the distance between them. You will also see some interesting consequences of this fact which may surprise you.

Go to the terminal now for a quiz covering this lecture.

Lecture 20 - Electrostatics

Demonstration lecture, using the film loops nos. 281, 283, 290.

In the last lesson you saw a film about Coulomb's law which demonstrated that the mathematical expression for the force between two charged bodies is an inverse square law; that is, the force is inversely proportional to the square of the distance between them, and the force acts along the line between the bodies. Electrical forces are sometimes attractive, sometimes repulsive, as was pointed out in Lecture 19.

We mentioned, too, that glass rods which have been rubbed with silk exert forces of repulsion on each other. Also, rubber rods which have been rubbed with fur repel each other, but the rubbed glass rod ATTRACTS the rubbed rubber rod. This seems to indicate that there must be different kinds of electricity, a fact that has been known for centuries.

Some demonstrations of these forces are given in the film loop 80-281 "Introduction to Electrostatics." Let me describe briefly what's in the film before you go look at it.

First, you'll see that when a piece of plastic rubbed with a cloth is held over a pile of light, uncharged particles, they jump up to the plastic. The slow-motion movie demonstrates something we've heard before about the relative strength of electric and gravitational forces: electric force pulling on the small particles is clearly much larger than the gravitational forces exerted by the earth on the particles.

Next, small bits of charged plastic, suspended from threads, are tested near other charged bodies. You'll notice that bodies with unlike charges attract each other; with like charges, they repel.

Finally, two rods (one plastic, one glass) are charged up and brought near some charged pieces of plastic. The two rods have opposite effects on the plastic bits showing that the rods have opposite types of charge.

Remember when we say that a body is charged, it is the same as saying it has a "net" of "excess charge" -- that is, more of one type of charge than the other.

Now, please ask the proctor for film loop 80-281, "Introduction to Electrostatics."

These two types of electricity we've been demonstrating must for convenience be named something shorter than "rubber-rod-rubbed-with-fur" and so on. A useful set of names is "positive" and "negative," for the glass-rod charge and rubber-rod charge, respectively. This usage dates back to Ben Franklin, something he tossed off between flying kites and inventing spectacles. The names are arbitrary, but in some ways fit neatly into electrical calculations, as you'll see as we go on. Using these terms then the phenomena demonstrated in film loop 281 can be summed up by saying that two positive charges will repel each other; two negative charges will repel each other. But a positive charge and a negative charge will attract each other. To make it even shorter: "like charges repel; unlike charges attract." You'll remember that Coulomb's law gives a way of calculating the magnitude of the force between two charged bodies and that the direction of this force is along the line between the two bodies. If a positive and a negative body are placed near each other, and only one of them is free to move, the Coulomb force will cause the free charge to be accelerated toward the other charge; they will try to get as close together as possible. Similarly, two like charges will be accelerated away from each other. We will define a force of repulsion as a positive force and a force of attraction as a negative force. Notice how this works out in Coulomb's law with the signs of the charges. Two positive charges multiplied together give a positive (repulsive) force. Two charges of differing sign when multiplied together give a negative (attractive) force. So this convention for handling signs is a great help in keeping straight the directions of the different forces when working electrostatic problems.

Because all matter contains charged particles, these electrical forces exist in all matter and are the forces that hold matter together. The atom consists of a positively charged nucleus surrounded by negatively charged electrons. Charged particles can move more easily about in some substances than in others. A CONDUCTOR is a substance in which the charges can move about freely; in an insulator, the charges are not free to move. However, an object of either type can be charged up by placing excess charge on its surface by some process like rubbing it with fur or placing it in contact with another charged body.

Conductivity of Gases and Liquids

You know that some solids, such as copper, are conductors. Others, like bakelite, are insulators. What about liquids? And gases? Under ordinary circumstances gases, including air, are insulators. Their molecules are very free to move, but do not transfer any net charge because the molecules are electrically neutral. But if we direct a beam of X-rays at the gas, some of the gas molecules are separated into positive and negative parts, called ions. The gas is then called an IONIZED gas and in this condition the gas behaves as a conductor. The movement of the charged pieces of molecules can result in a net flow of charge.

While ALL GASES are insulators under ordinary conditions (that is, if they are not ionized), SOME LIQUIDS are conductors. Those liquids which conduct do so because of the presence of charged particles. If, e.g., salt is added to water, the salt spontaneously breaks up into ions in solution and it is these ions which give the liquid its ability to conduct. Pure water for example is a poor conductor--but don't depend on this when handling electrical equipment while standing on a wet floor. Most water contains some dissolved impurities which ionize and conduct electricity quite well. The interesting difference between liquids and gases is that liquids which contain impurities, such as salt, need NO outside ionizing agent to conduct; the ions form spontaneously in solution.

The Electroscope

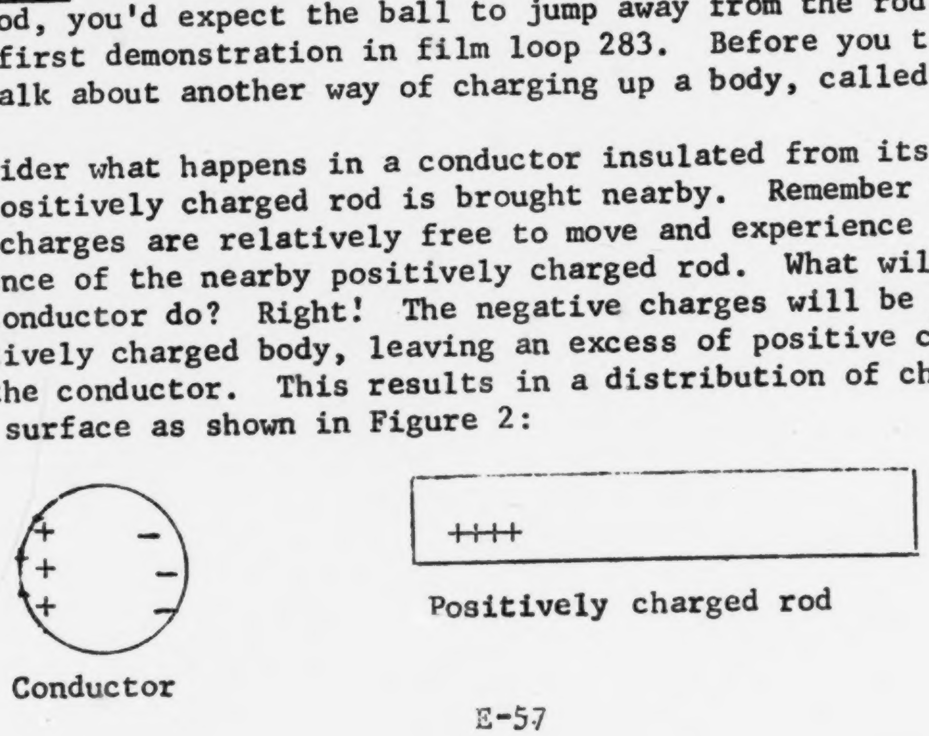
In these experiments with charged objects we will need an instrument that can detect the presence of an electric charge. One such device is the electroscope which consists of a conductor (e.g., a metal rod) well insulated from its surroundings. Hanging from the rod are two thin gold leaves. Look at Figure 1 showing the metal rod stuck through an insulating "cork" in the top of a glass jar. This is how it works. If we touch the conducting knob at the upper end of the metal rod with a charged piece of plastic, the two gold leaves spring apart. Why should this happen? Well, some of the excess charge from the plastic is shared with the metal rod. Since the metal rod is a conductor, these charges are free to move and they move as far away from each other as possible because of the Coulomb force of repulsion between like charges. We now have negative charges distributed all the way from the knob, down the rod, and on the two gold leaves. Hence, these two leaves are both charged negatively and, consequently, exert a repulsive force on each other. Being light in weight, they spring apart.

If we now touch the knob with a finger, the excess charges drain away to the earth which contains so many charges that it is, in effect, a large reservoir of charge, capable of accepting an unlimited amount of charge of either sign from any ordinary charged body. The gold leaves fall together again and the electroscope is no longer charged. This process of sharing charge with the earth is known as grounding. Suppose we now touch the knob with a positively charged body? Now the charge distributed throughout the rod and gold leaves is positive. Again the Coulomb force between the gold leaves is repulsive and the leaves spring apart. So you see that you can tell by looking at the leaves whether or not the electroscope is charged, but you cannot tell just by looking what is the sign of the charge. Later in this lecture we'll describe an experiment to determine the sign.

Charging by Contact and Charging by Induction

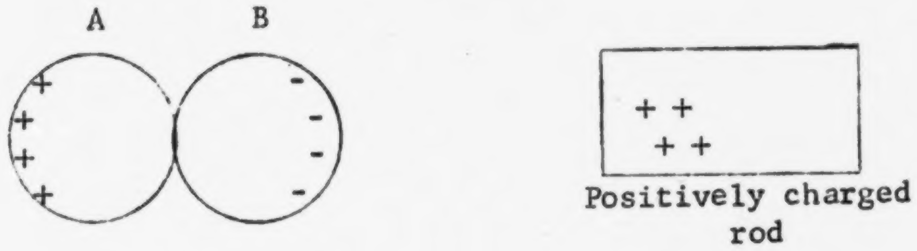
Both insulators and conductors can be charged by placing excess charge on their surfaces by some process like rubbing with fur or bringing it in contact with another charged body. Now when bodies are charged by contact they share the excess charge of the charged body and, consequently, have the same type of charge as in the body contacted. But two bodies with the same type of charge repel each other. So if you touched a small conducting ball with a charged rod, you'd expect the ball to jump away from the rod. This is shown in the first demonstration in film loop 283. Before you take a look at this, let's talk about another way of charging up a body, called induction.

Let us consider what happens in a conductor insulated from its surroundings as a positively charged rod is brought nearby. Remember that in a conductor the charges are relatively free to move and experience a force due to the presence of the nearby positively charged rod. What will the charges on the conductor do? Right! The negative charges will be attracted toward the positively charged body, leaving an excess of positive charge on the far end of the conductor. This results in a distribution of charge on the conductor's surface as shown in Figure 2:



Suppose our conducting body consisted of two balls in contact with each other as in Figure 3. Call them A and B, and bring the positively charged rod near B. Now the negative charges will be attracted toward the rod and there will be an excess of negative charge on B, leaving a lack of negative charges, i.e., a net positive charge on A.

Figure 3



Keeping the rod in place we separate A and B. After they're separated, even if you remove the charged rod, A and B will remain positively and negatively charged, respectively, since there is no way for the charges to flow back into a balanced distribution.

These two methods of charging a body (contact and induction) are shown in film loop 80-283.

The first demonstration is charging a ball by contact with a positively charged rod, after which the ball carries a net positive charge the same as the rod and is, therefore, repelled by the rod.

We'll use this positive ball to test the charge of two spheres charged by induction as described a minute ago. The charged rod is brought near one of the two spheres which are in contact with each other; the spheres are then separated with the rod still in place. The spheres should now both be charged, but with opposite signs as shown in Figure 3. Notice in the film that the positively charged test ball is repelled by sphere A (the sphere originally further from the charged rod) and is attracted to the other sphere. If the spheres are now brought together and the ball grounded, there is no attraction between the ball and either sphere. The ball's excess charge has been neutralized by negative charges drawn from the ground, and the positive and negative charges on the spheres have redistributed themselves between the two spheres so that either carries a net charge any longer.

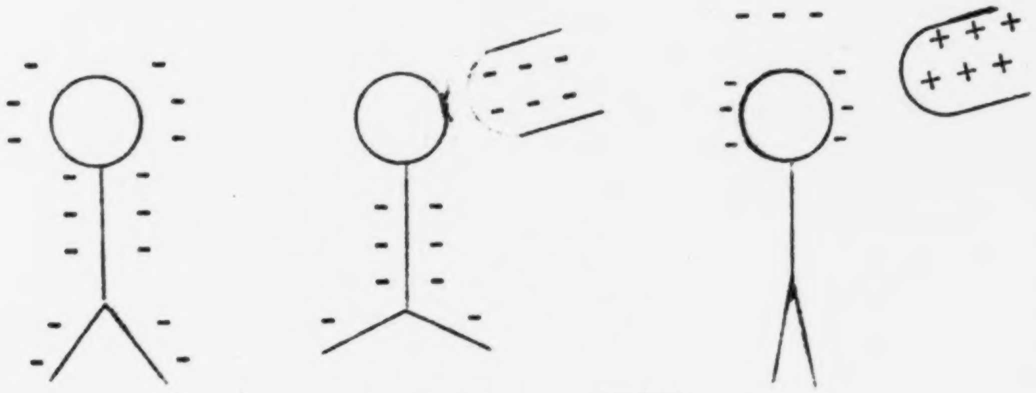
Suppose instead of two spheres we use one sphere and my closed fist substituting for the sphere further away from the rod. Again the sphere will have an excess negative charge; but the excess positive charge on my fist, instead of remaining on the conducting surface of my fist, is neutralized by negative charges flowing from the ground because I am not a very good insulator. Now I remove the fist before the positively charged rod is withdrawn. This leaves a net negative charge "stranded" on the sphere and we have by the process of induction charged the sphere with a charge opposite to that of the rod. This is in contrast to the earlier demonstration in which we charged the sphere by contact with the positively charged rod, and the sphere ended up with the same type charge as the rod. If only one finger is used to touch the sphere, we see that the result is the same--the sphere remains with a charge opposite in sign to that of the rod. The point of this whole film loop is this: to demonstrate that objects charged by contact have the same type of charge as the objects with which they were contacted, whereas objects charged by electrostatic induction have the opposite charge. Now please go look at film loop 283, and be sure you understand each of the experiments; you may want to look at the demonstrations in the film loop again, or listen to this lecture again.

Now that you understand it, let me ask you a question. In the demonstration with the closed fist touching a sphere near the charged rod, if the rod is moved away before the fist is removed, what type of net charge is left on the sphere? I'll wait a minute while you figure that out.

Let's see what the answer to that question is. The experiment was to hold a positively charged rod near the sphere with my fist touching the sphere on the other side. In the film, the fist was removed before the rod leaving a net charge "stranded" on the sphere. This charge had no way of leaving the sphere even after the charged rod was removed. In our question this time, the fist is moved away only after the rod is removed. That means there is a time interval after the removal of the rod, during which any net negative charge induced on the sphere can "run away" to ground through the connection supplied by my fist. The answer to the question then is: no net charge is left on the sphere. So any time you're asked about the charge left on a body, check the experiment carefully to see if the body was grounded, or neutralized, after all charging agents have been removed.

Now that you understand about charging by induction, you're in a position to do the experiment we promised to determine the sign of the charge on an electroscope. Remember earlier we said that you could look at an electroscope and tell if it was charged by whether the gold leaves were standing apart from each other, but you couldn't tell the sign of the charge by looking at it. Now look at Figure 4 showing a skinny diagram of an electroscope and some charges on it. Suppose it has a negative charge to start with. If you bring a negatively charged plastic rod near the knob of the electroscope (not touching it) the leaves diverge even more as more negative charge is repelled away from the knob. If, instead, a positively charged glass rod is brought near a negatively charged electroscope, negative charges from the leaves are attracted toward the knob, leaving less net charge on the leaves which therefore collapses

Figure 4



If the electroscope had originally been positively charged, the reactions to the two rods would be reversed.

Electrostatics is the basis for many kinds of interesting phenomena, as you know if you've ever slid across a car seat on a dry day and then reached for the door handle. Now that you understand about charging up bodies, you may be able to avoid a few shocks by grounding yourself to that door handle while sliding across the seat. If you do build up a large charge on that car seat, try discharging it through the flat palm of your hand instead of through your fingertips--it hurts less when the electrons have a large area to discharge through.

Some tricky applications of these properties are shown in the last film loop for this lecture. There are four demonstrations on this film and you're welcome to see them all and read the descriptions of the film box; but we're mainly interested in the first two. First you'll see an electrophorus (this is the "ancient charging device" used by Eric Rodgers in the PSSC movie on electricity). This device consists of an insulating sheet such as plastic which can be electrified by rubbing, and a metal disk down on the charged-up plastic sheet and touch the top of the disk with your finger. What happens? The same principle as those two metal spheres charged by induction. The charges on the plastic sheet induce charges on the underside of the disk. You touch the top of the disk with your finger grounding this surface. Then remove the disk from the plastic sheet, leaving a net charge on the disk. This disk can then be used as a source of charge itself, for example, by touching it to a third body which you want to charge up. This will deplete the charge on the disk, but you can come back repeatedly to get another "load" of charge.

The second demonstration is the hand chime: a small styrofoam ball coated with conducting paint, and suspended by a nylon thread. When you hold it near a source of charge (such as the disk from the electrophorus) it swings back and forth between the disk and your hand like the clapper in a bell. It is shown in slow motion in the film loop. The mechanism is this: the highly charged disk induces a charge of opposite sign on the ball which is therefore attracted to it. When it touches the plate, it shares by contact the charge on the disk and is now strongly repelled since it now has charge of the same sign as the disk. When it is repelled far enough to hit the hand, it is neutralized by this "ground" connection and the whole process repeats itself.

Now please ask the proctor for film loop 80-290, "Problems in Electrostatics." After you view it, see if you can go through the explanation of the electrophorus and the hand chime. If not, you may want to listen again to this part of the tape. After you have finished with this film loop, please come back for the brief finale to this lecture.

Batteries

We've been charging objects by rubbing plastic with wool and transferring some of the excess charges to the desired object. A convenient device to have around is a battery which separates charge by chemical means instead of mechanical rubbing. Some batteries can be used to charge up a gold leaf electroscope. Inside the battery, chemical action separates the positive and negative charges and causes the plus charges to move to the positive terminal despite the Coulomb force which is constantly attracting them to each other. If a conductor is connected between the battery terminals, negative charges will flow to the positive terminal. The chemical action inside the battery will continue to pump more negative charges back to the negative terminal.

Lecture 21 - The Electric Field and the Elementary Charge

In a previous lecture, you were introduced to the notion of electric charge in a rather qualitative and informal manner. You were shown how some types of materials, when rubbed against certain other materials, acquired the ability to attract or repel each other and certain other objects. This newley-acquired property was attributed to something we chose to call electric charge, and which we claimed had been transferred from one material to the other during the rubbing process. We further made the statement that this so-called charge came in two varieties--positive and negative--and that similar charges repelled each other, while opposite charges attracted each other. Nothing was said about the actual quantities of charge involved in the simple examples we gave, although we did mention that charge comes in fundamental, or elementary, units which you would learn more about later. At the end of this lecture, you will see a movie which deals with the elementary negatively-charged particle. For the moment, we will merely state that when we will be speaking of charged bodies, we will usually mean ones which are carrying a good deal more than one such unit.

Another topic we took up last timewas the Coulomb electrostatic force between two stationary charged "point" bodies. (The term "electrostatic" is used in reference to stationary charges; a point refers to an entity whose physical dimensions are zero.) We saw a movie that took up this matter in detail, and we found that the force between two such charged bodies, $F = \frac{KQ_1Q_2}{R^2}$ (with the symbols the same as in the last lesson), could be thought of either as the magnitude of the force exerted by Q_1 on Q_2 or the magnitude of the force exerted on Q_1 by Q_2, both forces existing simultaneously.

Well, so far, so good; everything looks nice and simple. But now, say that there are more than two charged bodies involved. What then? The principle at least is simple. In such a case as that, you simply have to look at the forces between the individual pairs of charged particles and add them up vectorially in order to get the total force on one particular particle. If there are only a few particles involved, this is a simple matter. For example, say we have three unit point charges, A, B, and C, and we want to know the net electrostatic force on A. At this point, it might be a good idea to look at your supplement, Figure 1a, where an example has been worked out for you. How do we go about finding the net force? We consider the pair A, B and the pair A, C; we find the force on A due to B and the force on A due to C, and then add them up. Now look at Figure 16 which illustrates a different arrangement.

This method will work for any number of charges; however, as you can see, the more charges that are involved, the more tedious the calculation becomes. Since frequently we do have to deal with very large numbers of charges, we would have a sad mess on our hands if we didn't find a way around performing all those individual calculations.

Fortunately, there is a convenient way out. We introduce a new concept which often proves very helpful. This concept is the electric field.

What is an electric field, exactly? Well, it's an experimentally known fact that electric charges interact with and affect each other. In particular, a quantity of electric charge, in the vicinity of another charge or collection of charges, experiences a force due to this charge or charges. We define the electric field E to be the electric force experienced by one unit of positive charge. A charge of magnitude q, therefore, would experience a force F given by the equation

$$\bar{F} = \bar{\bar{qE}}$$

$\bar{E}$ is also referred to as the electric field strength.

Now, for a simple example, look at Figure 2. Recall the Coulomb force, $F = \frac{KQ_1Q_2}{R^2}$

Let us assume that Q_1 and Q_2 are two point charges of arbitrary magnitudes separated by a distance R. Then we say that the electric field due to Q_1, as $E = \frac{F}{Q_2} = \frac{KQ_1}{R^2}$. By a similar calculation, the field due to Q_2 is

$$E = \frac{F}{Q_1} = \frac{KQ_2}{R^2}$$

Although Q_1 and Q_2 can have many magnitudes, we did take the precaution of making them point charges so that the distance R between could be clearly defined. Notice that the magnitude of the field varies from point to point, since R, the distance from the field-producing charge, enters into the equation.

There will be a short pause for you to study Figure 2. Note carefully that an electric field is defined with reference to the force on a movable test charge placed within it. This test charge has nothing to do with setting up the field; it is merely acted on by the field. The field itself is set up by a charge or group of charges which are thought of as stationary, and the field exists even in the absence of a test charge. It is independent of the test charge.

At this point, it may occur to you to wonder: what about a distribution of stationary charges which cannot be thought of as a point? Do they also produce a field around them? Of course! Such a field is much more complex and difficult to describe than that produced by a point charge, but it does indeed exist, and we must, therefore, find a way to describe it. Fortunately for us, there exists a convenient method of describing any electric field. This is by means of lines of force. Imagine that we place a positive test charge in an electric field at some point. It will experience a force, and if we move the point continuously in the direction of this force, we will trace out what is called a line of force. If we do this a number of times, starting at a number of different spaced points, we can trace out a series of such lines of force, giving us a "map" of the field.

You will find some pictures of lines of force in your supplement, Figure 3.

Notice that the lines of force are numerous in regions where the field is strong, and less numerous where the field is weak. The direction of the field at any point is tangent to the line of force at that point. (It is to be stressed here that lines of force do not exist as an actual, physical entity, but are simply a convenience to aid in our visualization of the behavior of the field.)

Note that for a field set up by a distribution of charges, the force on our test charge at any given point is the vector sum of the forces exerted on it by each of the individual charges.

The usefulness of the electric field concept in working certain kinds of problems is obvious. If we know the value of E--and that can be measured experimentally as well as calculated--then we can find the force on a charge placed in this field simply by multiplying E by Q, the magnitude of the charge. If we want the force on a charge twice this large, we multiply E by 2Q; and so on. We'll say that again. If you know the electric field E at any point, you can calculate the force on a charged body placed at that point by multiplying $\bar{E}$ times the size of the charge 1Q. In other words, $\bar{F} = (Q)\ (\bar{E})$.

One particular type of electric field in which we are frequently interested is that which appears between two parallel metal plates when one of them has positive charges distributed uniformly over its surface and the other has an equal number of negative charges so distributed. Such a device is called a parallel-plate capacitor; and you will be hearing more about it in the next lecture. This device used to be called a condenser but the preferred name is now capacitor. It turns out that the field between the two plates is uniform; what this means is that a test charge experiences the same force no matter where it is placed between the two plates. The lines of force in this case are simply a set of straight lines evenly spaced running between the two plates and perpendicular to both, except near the edges, where there is some bending. You'll find an illustration of this in the supplement, Lesson 22, Figure 1.

Well, that is about all we're going to say about electrical forces and fields for the time being. Now at last we are finally ready to discuss the elementary charge which we referred to briefly, earlier. Remember, we promised we would get back to it later? We are not going to disappoint you.

If you remember your reading assignment, you will recall that during the latter part of the last century, a great many experiments were performed with what were called discharge tubes. Gas-filled tubes would glow and their glass walls would fluoresce under certain experimental conditions. It was found that these effects were being caused by something passing through the tube between two metal terminals and it was furthermore found that this something could be deflected by means of an electric or magnetic field. This latter fact strongly suggested that what was passing between the terminals was a stream of some kind of particles, and the direction of deflection indicated that they were negatively charged. Scientists became quite interested in these electrons, as they were later called, and performed many experiments in order to learn more about them. In 1897, the British physicist J. J. Thomson was able to show that the charge to mass ratio of the individual electrons was always the same. He could not say what either the mass or charge was, however, only the ratio and it remained for someone else to actually measure the elementary charge. This was finally done by Robert Millican in 1909, in a famous experiment in which he not only measured the charge of the individual electron but showed that all electrons have the same charge, as well as the same mass. An experiment similar to his is performed in the film you are about to see. This experiment is a bit advanced, but with careful concentration, you will be able to follow it. The basic idea of the experiment can be demonstrated in two steps:

(1) An extremely light object (in this case, a small plastic sphere which has been electrically charged) is injected into the space between two charged metal plates, where there is a uniform electric field. The net force on the sphere is the vector sum of the weight of the sphere and the electric force due to the field. The velocity of the sphere is shown to be proportional to the next force acting on the sphere.

(2) The number of charges on the sphere is changed (in this case, by means of X-rays). The electrical force on the sphere is, therefore, changed and as a result, the velocity changes. Many such changes are observed, and are shown to be integral multiples of a certain fundamental value. From this it is inferred that there is an elementary unit of charge.

In film 404, the Millican Experiment, you will see how such an experiment is set up and measurements taken.

Go to your terminal now for a quiz on this lecture. When you have finished with that, watch film 404, and then report back to your terminal for a review.

Lecture 22

Today we're going to talk about electric energy and currents. In lesson 20, you learned about the Coulomb force and were introduced to the concept of an electric field. It was pointed out that the nice thing about the field concept is that it often makes things much easier to visualize than the mutual force idea, in which you get a rather cloudy picture of two charges somehow doing the same thing to each other. If the electric field, E, is known, from direct measurement or calculation, you can figure out the force on a charged body, (placed in that field), directly from the $\vec{F} = q\vec{E}$ equation, without adding up a lot of individual force reactors. This happens to be just what you usually want to do in experimental situations, so it's fortunate that things work out this way. For example, an arrangement very commonly seen in the laboratory consists of two parallel metal plates having equal but opposite charge, and separated by a distance d. A uniform electric field is created in the space between the plates and this field is the result of many, many charges on the two plates, not just one pair. You'll find a picture of this device and the field it creates in Figure 1 of your supplement. The more charges that are involved, the stronger the field will be. But all we are concerned with is the behavior of one test charge which has been inserted into the field. A charge inserted between the two plates will experience a force which we will call F. It is convenient to define the amount of force per unit charge as the field strength E, $E = F/q$, as we said before.

Let's take a closer look at this parallel plate device. We will first enclose it in a vacuum to eliminate the effects of air. Since its field is uniform (except in the vicinity of the edges), a particle bearing a charge q and inserted between the plates will experience a constant force no matter where it is placed, provided that it not be too near the edges of the plates where irregularities in the lines of force occur. That force, which is simply equal to qE, will cause the particle to accelerate. Let us say that q is a positive elementary charge and we have placed it right at the positive plate. It will start to move in the direction of F, which in this case is directed along the line of force at that particular point (see Fig. 1 again.) As it accelerates, it is, of course, gaining kinetic energy, since its velocity is increasing. Finally, it arrives at the negative plate with a velocity v_f. Now let's say we want to do the opposite thing: we want to push it back away from the negative plate until it is exactly next to the positive plate again. If we somehow set it in motion with a velocity the magnitude of which is $v_o = v_f$, we will see it travel toward the positive plate, slowing down as it goes, until, when it just reaches it, it has come to a complete standstill. The kinetic energy has all been lost, but it is clear that some kind of potential energy has been gained, since if we were to release it now, it would spring right back to the negative plate.

It can be seen, then, that the electric field can be thought of as a sort of reservoir of electrical potential energy which becomes available to any charged particle which happens to come along. How much energy? Well, let's remember that we've just seen from an example how potential energy was changed entirely to kinetic energy and vice versa. The work done in this transfer is equal to F times d, where d is the separation between the plates. The work done by the field must equal the kinetic energy gained, so $Fd = (1/2)mv_f^2$ where v_f is the final velocity of a positive particle just as it reaches the negative plate. Notice that both the kinetic and potential energy depend upon the particle's position at any given instant.

The difference between the potential energy a particle of unit charge had when it started out at the positive plate and that which it had when it reached the negative one is called - understandably enough - the potential difference. If $Fd = qEd$ was the potential energy available, then $qEd/q = Ed$ was the potential energy available per unit charge. This quantity is known as the "electrical potential", or sometimes simply "potential". Its unit of measurement is the volt; one volt is equal to one joule per coulomb of charge. Care should be taken with this definition. Notice that one coulomb represents considerably more than one elementary charge. Your supplement sheet, page 2, will clarify this point.

Up to now, we've been concerned exclusively with the behavior of individual charges. There are, of course, also group activities, and these are in general far more noticeable in everyday life. When a bunch of fundamental charges (and by convention, we usually assume them to be positive) get together and start flowing, they're called a current. Of course, even a single lonely charge in motion constitutes a current, but it's a very feeble one because the fundamental charge is a very tiny thing and you have to get quite a few of them together before they start to show up appreciably on the ordinary everyday level. A material which allows such a stream of charges to pass through it easily is called a conductor; metals, particularly copper and silver, are very good conductors. Current is formally defined as the quantity of charge passing a given point per unit time, and is measured in amperes, a rather large unit.

Current and voltage are frequently confused by the laymen. If your household is wired for the usual 110 volts, this means that the electrical potential difference between the two terminals (the prongs of a plug) is such that 110 joules of work will be done for each coulomb of charge moving between those terminals, but the current flow is an indication of how many of those charges are moving.

There is another concept which is very important in electric theory and practice. This is resistance, and it will enter into the discussion in a very natural way a little bit later. For the present, we can just say that it is the tendency of a material to resist a current flow. When a current flowing across a constant voltage drop encounters a large resistance, the elementary charges comprising it continue to move, but they are forced to slow down. Thus fewer of them pass a point at a given time, and we say the current decreases. Some of the potential energy which would have been converted to kinetic energy if they had continued to move at their former, more rapid pace, must then be dissipated in some other way. As it happens, the lost kinetic energy emerges as heat. Although resistance is what makes electrical parts consume expensive electric power converting it into heat, it isn't all that bad to have around. In fact, many of our commonest electrical appliances take advantage of its effects. All heat-producing appliances like irons and toasters are large power consuming devices.

Now that we have some idea about current and voltage and resistance, let's take a look at some electrical circuits. We will use a battery and a conducting wire (see diagram 2 of your supplement) to set up an electric field between the battery's two terminals. For our purposes, a battery is a device which supplies a constant amount of electrical energy per elementary charge. This quantity (the energy per charge) is called the emf of the battery, and is measured in volts. A volt is defined as 1 joule per coulomb. It is given this special designation to indicate that there is a potential *jump* (that is, an increase) between the two terminals of the battery, as opposed to potential *drops* in other parts of the circuit. In other words, chemical processes within the battery are providing a constant store of potential energy which is then used (and eventually dissipated) by other parts of the circuit. When we speak of the voltage of a battery, though, it is the emf we're referring to.

In a battery, we assume that positive charges are pumped up from the low voltage (negative) terminal to the high voltage (positive) terminal. The negative terminal is taken to be the zero point of potential energy. Then, as they (the charges) enter the wire and travel through it, they begin to lose their potential energy. They "fall" around the wire. In fact, in making a trip around the circuit, they lose an amount of potential equal to the emf of the battery, so that by the time they get back to the low voltage terminal, they are also exactly back to where they started in terms of energy, and the cycle is repeated. The result of all this is a continuous flow of charge-- or current--in the conducting wire.

Now if the *emf* is in volts, then *q(emf)* is the energy, in joules, being supplied to the circuit by the battery. Since $q/t = I$, $q = It$, and the energy is $It(\underline{emf})$. But power is energy per time. Therefore, Power = $It(\underline{emf})/t = I(\underline{emf})$.

Say now that a current is moving through a circuit, losing potential as it goes. Between two arbitrary points 1 and 2 (see Figure 3 of your supplement), it experiences a voltage drop V_{12}. Is this drop related in a simple way to I? It turns out that it is. Careful measurements by the

19th century experimenter Ohm showed that for simple circuits, V is proportional to I. When a constant of proportionality R is added, $V_{12} = IR_{12}$ (diagram 3) and indeed, for the whole circuit, emf = IR. The general relationship V = IR is known as Ohm's Law. The constant of proportionality R is none other than the resistance, which we touched on earlier. In the foregoing equations, (consult your supplement if you need to), R without a subscript refers to the resistance of the entire circuit. Actually, the battery provides some resistance of its own - the so-called "internal resistance". For our purposes, we will assume that this quantity is negligible compared to the circuit resistance. No circuit, no matter how carefully constructed, can ever be made entirely free of resistance even if this were desirable (and we have seen that in may cases it is not). The same holds true for the internal resistance of a battery.

A few minutes ago, you learned that Iemf is the power being supplied to the circuit by the battery. It is also of interest to us to know how much power is expended in heat production in the circuit. This heat production takes place in the resistors, where electrical energy is converted to heat energy.

In a circuit whose total resistance is R, $I = \frac{V}{R}$. Or, since V = emf, I = emf, and emf = IR.

Now, power had dimensions of energy per time, while emf has dimensions of energy per charge.

Thus, to transform emf = IR into a power equation, we multiply both sides by $\frac{q}{t}$, and get: $P = I(\frac{q}{t})\ R$,

but $\frac{q}{t} = I$. Therefore, $P = I^2R$,

and since IR = emf, P = Iemf). But this is simply the equation for power supplied to the circuit by the emf of the battery. So, we notice an interesting thing; namely, that power (and hence, energy) is conserved in an electric circuit. The power used up in heat production is exactly equal to that supplied by the battery. So the law of conservation of energy applies to electrical as well as the mechanical systems you studied earlier.

Power can also be expressed by the relationships:

$$P = IV \text{ and } P = \frac{V^2}{R}$$

These are easy to derive from the $P = I^2R$ equation and Ohm's Law, and we'll leave that as a problem for you to do by yourself. Here they are again:

$$P = IV \text{ and } P = \frac{V^2}{R}$$

Now please report to your terminal for a review.

Lecture 23 (E IV)

In the last lesson, we talked about electric energy and currents. Today we introduce a new topic: magnetism. Actually, magnetism is not so new in fact, it's very closely related to electricity. Practically everybody is at least vaguely aware that there is a connection between them. For instance, in your 7th grade general science class you probably had a chance to see somebody wind a coil of copper wire around a nail and connect the ends of the wire to a battery of some kind. Then you saw that the nail became magnetic: i.e., it would attract, or pick up certain types of metal objects. This, of course, was a very simple electromagnet. If one of the wires was disconnected from the battery, the nail lost its magnetism at once. In today's discussion, we'll investigate in detail just what exactly the relationship is between electricity and magnetism.

We're all familiar with at least one manifestation of magnetism. Everybody knows that the needle of a compass lines up in a north-south direction. If we deflect the needle somehow and then release it, it will swing back to its "natural" position. Even if we rotate the mounting, the needle maintains its direction. We customarily say that it points to the earth's north pole, and we call the north-directed end the north pole and the south-directed end the south pole. Actually, this terminology is not very satisfactory. It would be better to call the ends the north-seeking pole and south-seeking pole, respectively, but this is the nomenclature that has come down to us, and we will use this conventional one.

A compass is simply a lightweight magnet mounted on a delicate pivot to allow it to move easily. So the "pole" terminology, coined originally to apply to the behavior of a compass, can be carried over for all magnets.

If we were to try to make a compass needle out of a toothpick, we wouldn't be very successful in getting it to work. Evidently only certain materials can be used for this purpose. We call them "magnetic", and we say that they create around them a magnetic field, just as charged particles create an electric field. The earth itself is a magnetic object.

So far we've said very little about the magnetic field except that it exists. Let's take a closer look at it. In a previous lesson, you were introduced to the idea of lines of force in connection with the strength of an electric field.

The pattern of lines of force for a system consisting of one positive and one negative charge is illustrated in your supplement sheet, Figure 1a. Look it over carefully.

Now, what does a magnetic field look like? If you were to lay a sheet of paper over an ordinary bar magnet (keeping the paper flat by appropriate supports) and then sprinkle iron filings on the paper, you could obtain a pattern of the magnetic field by gently tapping the paper. Most of the

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Now, what does a magnetic field look like? If you were to lay a sheet paper over an ordinary bar magnet (keeping the paper flat by appropriate pports) and then sprinkle iron filings on the paper, you could obtain a ttern of the magnetic field by gently tapping the paper. Most of the filings will line up right along the magnetic *lines of force*, creating a very clear pattern of the field. This pattern is *also* reproduced in your supplement (Figures 1b and 1c).

One thing you'll notice right away is that the pattern is quite similar to the one produced by the two oppositely charged objects in Figure 1a. But there is one very important difference, and this will help to clarify the distinction between electricity and magnetism. With the magnetic field, the lines of force actually pass through the body of the magnet. In other words we can say that *magnetic* lines of force close in upon themselves, or form *closed loops*, while *electrical* lines of force *terminate* on the charges. This is the first important point to keep in mind.

This brings us to our second point. No one has ever yet been able to isolate a magnetic pole. Although electric charges are easy enough to separate, magnetic poles always come in pairs. If you chop a bar magnet in half, you get--not one north pole and one south pole, but two bar magnets, each with a pair of poles. We'll go into the reason for this later on. As with electrical charges, two similar types repel each other, while a pair of opposites attract each other.

Now that we know what a magnetic field looks like and have an idea of what it does, we're ready to see how it is related to electricity.

We could derive the relationship mathematically, using a series of complicated equations, but since the math involved is above the level of this course, we're going to go a different route. We'll just make certain postulates about magnetic fields, and then demonstrate them experimentally.

Our first postulate is:

Moving charges produce magnetic fields.

This will be demonstrated with two simple experiments in the following film loops. In the first experiment, a small compass is held next to a wire. When the ends of the wire are attached to the terminals of a battery, setting up a current--that is, a stream of moving charges--the compass is deflected. When the terminals are switched, reversing the direction of the current, the compass is deflected in the opposite direction. This effect is due to the fact that a magnetic field has been set up around the wire due to the current flowing through it. Now, please go look at the film loop, FSU-33. Lecture 23b as you might expect, there is a direct relationship between the magnitude and direction of the current and the magnitude and direction of the magnetic field it produces. It is found that for the case of a long straight conductor carrying a current, I, the magnetic field at a distance, d, at right angles to the conductor is:

$B = 2 \times 10^{-7} \frac{I}{d}$ where I is in amperes, d is in meters, and B is in webers per square meter. This relationship is also written down for you in your textbook.

The second experiment is similar to the first except that it looks more complicated. A bar magnet hangs between two large loops of wire. When a current is set up in the loops, the magnet immediately aligns itself with the field. When the direction of current is reversed, the magnet assumes the opposite orientation. This is shown in film loop, FSU-35, please view it now. You may wonder why two loops were necessary at all in that experiment. Actually they weren't! We could have used one but happened to have these two handy, and they do give a strong, uniform magnetic field along the axis of the two loops.

Now that we're convinced that currents do indeed set up magnetic fields, here's a handy way to remember the relationships between their directions. It will help to look at figure 2a while you listen to this. Imagine that there is a current flowing in a wire, and that you grasp that wire with your right hand (if you want to, imagine also that you're wearing a rubber glove so you won't be electrocuted). If your thumb is pointing in the direction of the current, then your fingers are curling around the wire in the direction of the magnetic field. This is called the Right Hand Rule and is a good thing to keep in mind.

Now we're ready for our second postulate, which seems reasonable from our analogy to the electric field situation. If electric fields exert forces on electric charges, we now postulate:

Magnetic fields exert forces on moving charges.

We have some experiments to show you which will demonstrate this. In the next film loop, you will see a small iron wire hanging in the magnetic field of a large horseshoe magnet. When a current is caused to flow in the wire, by connecting it to a battery, the wire swings up, out of the magnetic field. When the leads are switched, causing the current to flow in the opposite direction, the wire swings back in the opposite direction. Now ask for film loop FSU-34 and watch it carefully.

We can see that a force did act on the current-carrying wire placed in the magnetic field. The next example is designed to tell you more about this force, particularly its direction. This example is a stream of moving charges which are NOT in a wire, such as the electron beam in the tube of an oscilloscope or in the TV picture tube. These charges are simply traveling through an evacuated tube, and can be readily deflected by a magnet brought near the tube. The electrons are deflected in a direction perpendicular to their velocity and perpendicular to the magnetic field. You will have an opportunity to see this demonstrated in the PSSC

film on the "Mass of the Electron" in lesson 25; in this film an electron beam is deflected by a magentic field of known strength, and the resulting deflection is measured as part of an experiment.

This experiment on the direction of this force created by a magnetic field suggests another right hand rule to us. As shown in Figure 2b of your supplement. This rule is:

> If you hold your right hand so that the thumb is pointing in the direction of the current and your index finger in the direction of the field, then the force acts perpendicular to the palm of your hand in the direction in which your other fingers would naturally point.

After studying Figure 2b, you can see that if the north pole of a magnet deflects a stream of charged particles in a certain direction, a south pole of a magnet would cause a deflection in the opposite direction, because the direction of the magnetic field would be exactly reversed.

The magnitude of this force on a moving charge is given by qvB, where B is the field strength, and q and v are, respectively, the magnitude and velocity of the charge. Notice very carefully that since the force is perpendicular to the direction of motion, it neither speeds up nor slows down the moving charge and hence, does no work. It is purely a deflecting force. If you don't remember about deflecting forces, go back and review them; they are covered in detail in lesson 13.

In these examples the magnetic field B was at right angles to the direction of the current (or velocity of the charged particles). Suppose these two directions are NOT perpendicular to each other? Then the force would be given by $F = qvB_{\perp}$, where $B_{\perp}$ is the COMPONENT of B that IS perpendicular to v, the velocity of the charged particles. In the extreme case where magnetic field is PARALLEL to the velocity (or current), the component of B perpendicular to the velocity equals zero, so the force would be zero. Always remember, in applying that formula F = qvB, that B means the component of magnetic field PERPENDICULAR to the direction of the charge's motion.

Let's look for a mement at the arrangement in Figure 3 of your supplement, optimistically entitled "Magnetic Force can be used to turn a Wheel". Now, this frame doesn't look much like a wheel, but if we can show you how magnetic force can cause IT to rotate, you could probably extend this rotation, in your imagination, to the rotation of a wheel, or the rotor of a motor. If you'll apply the right hand rule to the two long sides (1) of this current-carrying frame, placed in the magnetic field B, you'll find that the force on one side is in a direction to push that side up out of the paper TOWARDS you, while the force on the other side, 1, is in the opposite direction, because the current on that side is flowing in the opposite direction, so the force is pushing that side into the paper, AWAY from you. This results in a ROTATION of the frame. I'll wait a minute while you try out the right hand rule from Figure 2b on this problem. See if you come up with the right direction for these forces.

We've explained that the force of a stationary magnetic field affects moving charges only. There is another possibility, however. If a stationary charge is placed in a moving magnetic field, it 'sees' the same thing as if it were moving and the field were standing still. So moving magnetic fields do exert forces on stationary charges. Again, the force is qvB. v now is the velocity of the field, and we see that it is the relative velocity of the charges and the field which is of importance.

By now, we're convinced that magnetic fields are associated with moving charges. Well, what about a substance we call magnetic--a simple horseshoe magnet, for example? It seems to be electrically neutral. Where are the moving charges there?

The answer lies in the atomic structure. You probably know that an atom consists of a heavy nucleus surrounded by orbiting electrons. Since electrons are elementary charged particles, each one whirling in its orbit constitutes a very tiny current capable of producing its own magnetic field. The following film loop FSU-36 demonstrates this effect--on a larger scale. A current is set flowing in a metal loop which is placed in an outside magnetic field. Watch it line itself up. Please ask the proctor for film loop FSU-36. After viewing it, please come back for the last part of the lecture. That film loop demonstrated that a small current-carrying loop lines up in a magnetic field, just as a small magnet does. The small loop of current sets up a magnetic field; in this respect it behaves like a small magnet itself. Let's see how this helps us understand an ordinary, permanent magnet.

We referred earlier to the fact that a toothpick would not make a very good magnet. Nor will the majority of other ordinary, everyday materials. The reason is this: in most substances, the atoms are arranged in such a way that all these little current loops take random positions and their effects cancel each other. In other words, on the average, for each magnetic field point in a given direction, another one can be found which points in exactly the opposite direction. But in some substances--particularly metals--the atoms can be made to line up with all their current loops assuming the same orientation. Then, instead of cancelling, the magnetic fields re-enforce each other.

It's useful hereto say a few words about permanent and temporary magnetism. There's a tendency in nature for the atoms and molecules in a material to assume random orientations. This is due to the presence of natural molecular or atomic vibrations inherent in all materials. As a result, substances tend to lose their magnetism after a while. When we magnetize a substance, what we do is to get the atoms lined up neatly in the way we described before. The amount of time they will stay in this arrangement, before becoming disorganized again, is called their relaxation time.

Some metals, such as silver, have such a short relaxation time that we cannot observe any magnetic properties in them on the every day level. Others, such as iron and nickel, have relatively long relaxation times, and we call them magnetic.

If we touch an ordinary magnet to an iron nail, the iron atoms line up, and the nail becomes temporarily magnetic, as you can see from the fact that the nail will now attract other magnetic objects. However, when the magnet is removed, the nail loses its magnetism almost at once.

We could make it retain its magnetism longer by subjecting it to a powerful, current-produced magnetic field for some time after the current was turned off.

Most of the magnets which we think of as truly permanent, though, are natural ones, such as magnetite. Magnetite is a form of iron ore which was subject to tremendous pressures within the earth during its period of formation. These pressures were sufficient to "freeze" the iron atoms in a magnetic arrangement.

From what you've learned up to this point about what actually causes magnetism, you can easily see why it is that magnetic poles can never be isolated. Even if we break a magnet down to its most basic atomic unit--one electron orbiting about a nucleus, we still have a magnetic field, due to that orbiting charge, similar to that produced by a magnet with a North and South pole.

Now please go to your terminal for some questions on lecture 23.

Lecture 24 - Induction

The subject of this lesson will be electromagnetic induction, and while the name may not be familiar to you, you make use of it everytime you turn on an electric motor, or for that matter use electricity which is produced in a generator.

You've probably already noticed that the lecture uses eight film loops--but don't panic! They are merely demonstrations of variations on a basic idea. After the lecture, look back through your supplement and you'll see that only a few basic concepts were introduced; the series of ingenious experiments will give you some idea of the far-reaching practical application of electromagnetic induction.

Ideally, you should see the film loops and hear the lecture simultaneously. The nearest we can come to that at this time is to decide in advance what to look for in each film and then have you take a look at that demonstration film before coming back to the tape recorder for the next description. Your supplement sheets will be helpful in pulling all this together for you.

In your last lesson you saw that:

(1) Magnetic fields exert forces on moving charges, and ($F = q\ v\ B_{\perp}$)

(2) Moving charges, i.e., currents produce magnetic fields. For example, ($B = 2 \times 10^{-7} \frac{I}{d}$) around a straight wire.

In the last lecture we learned that the magnetic field around a straight unit is proportional to the current in that wire. Now if we look at (1) and (2) and think about the fact that moving charges produce magnetic fields, the possibility may occur to us that moving magnetic fields may produce currents.

First of all, we ought to get a current due to the forces on the charges when we move a group of charges through a magnetic field. One way to do this is to grab a straight wire and move it through a strong magnetic field. The wire, being a conductor, has charges free to move under the influence of a force of type (1) previously mentioned. Therefore, moving such a wire loop in a magnetic field should cause a current to flow in the loop, if we've arranged the circuit so that the charges are free to move in the direction of that force. How can we detect this current if it is there? Let's make a small side excursion along about here to describe an instrument to detect small currents. This device, called a galvanometer, is based on something we learned about last time, that is, the tendency of a small loop of current-carrying wire to line itself up in a magnetic field. So to detect a small current in a circuit, we connect such a small loop of wire electrically into the circuit, so that the current to be detected flows through our small loop. The loop is suspended by a fine thread so that it hangs in a strong magnetic field, in such a way that when a current flows in the loop, it turns away from its normal position in order to try to line up with the field. This type of twist suspension is very sensitive, as you'll remember (I hope) from the Cavendish experiment movie in which a small gravitational force could be detected by the twisting of a long tape supporting one of the masses.

This sensitivity enables the galvanometer to detect very small currents. To make the twist easier to observe, we attach a small mirror to the suspending thread, and shine a light on this mirror. Then a small twist of the thread results in the reflection swinging way out on a scale mounted some distance away.

(See Figure 1.)

All right, we now have designed a device for detecting small currents in a circuit; we will call this device a galvanometer. You will see one in FSU film loop no. 32. It begins with an overall view of a galvanometer and its scale, followed by a close-up view of the working parts. Look carefully and you can see a wire loop mounted between the poles of a strong permanent magnet, and the small mirror mounted on the suspending thread. The "wire loop" in this case consists of many turns to increase the sensitivity. With no current flowing in the loop, this mirror throws a spot of light on the scale in the zero position. When the galvanometer is connected into a circuit and a small current is allowed to flow, the wire loop twists in the field, causing the mirror to turn a little. As a result, the reflected spot of light swings out to one side. If the direction of current flow is reversed, for example by reversing the leads on the battery, the spot swings out in the opposite direction. Now look at film loop FSU-32, the Galvanometer.

We'll use this gadget now to detect currents in circuits we're interested in, so now you want to focus your attention on the circuit to which the galvanometer is connected, and on the displacement of the spot of light as we perform experiments with this circuit. In film loop, FSU-11, the "circuit" now connected to the galvanometer is this big wire loop in the experimenter's hand. If this loop is moved through a strong magentic field, we expect that there will be a movement of free charges in the wire; that is to say, a current. As you shall see in this film, the spot of light does swing out, indicating the movement of charges in the current.

You should notice three things in this film loop. First, the galvanometer shows a deflection only while the wire is being moved through the magnetic field. If it is held still, even right between the poles of the magnet, where the field is strongest, there is no current, no galvanometer deflection. The second thing to notice is that the direction of the deflection depends on the direction of movement of the wire with respect to the magnetic field. Third, the size of the deflection depends on the speed with which the wire is moved.

Now, go look at film loop FSU-11.

So you see in that experiment, the direction and size of the current in the wire depended on the direction and magnitude of the wire's velocity with respect to the magnetic field. This idea will come up repeatedly in this lecture.

It really shouldn't matter to the charges in the loop whether the loop moves through the field or the field moves relative to the loop, so long as there is some relative motion.

So in the next film loop FSU-14, the circuit will be kept stationary and the magnet will be moved. The cirucit in this case is a ring-shaped coil of many turns of wire, connected to our galvanometer so that we can tell by the movement of the spot of light when there is a current in the circuit. Again, you will see that the amount of galvanometer deflection is a function of how fast you move the magnet, and the direction of galvanometer deflection (which is to say, the direction of the induced current in the wire) depends on the direction of movement of the magnet.

In the film, one end of the magnet is painted white, so you can keep track of which pole is being pushed in and out of the wire loop. You'll notice that when the magnet is turned around so that the opposite pole is being pushed in, the direction of galvanometer deflection is reversed for a given movement of the magnet.

Now, please view film loop FSU-14.

In each case, the relative movement of a wire loop and a magnetic field has resulted in a current flowing in the wire without the presence of a battery. This is called an induced current and the phenomenon is called electromagnetic induction. We have observed that the current depends on the speed with which we move the field or the loop.

As you might expect, the amount of current induced depends on the resistance in the circuit. Thus, two different loops moved under the same conditions (same magnetic field, same speed) would carry different amounts of current if they differed in the amount of resistance encountered by the charges as they try to move under the influence of the force.

Though the current in two such loops would differ, the quantity that is identical each time is the emf. For the same field and speed, the same emf is induced each time. In fact, even if the circuit is not closed--if our "loop" has a gap--the same emf or potential difference is produced across the gap.

This is a very useful effect, to put it mildly. The huge generators which provide the electricity without which modern man is so helpless are simply a great many loops of wire being turned, by mechanical action, in a magnetic field. This results in a large induced current flowing in the wire. The current is then distributed to the cities to run computers, tape recorders, and other elegant power-consumers. You can see the generators which supply Tallahassee's electricity by driving down to the city's power plant, located near the town of St. Marks. To show the same thing on a much more modest scale, we've a film loop showing a small generator, supplying current to a light bulb. (Don't run it yet, just hang onto this information for a few moments). The bulb lights up when mechanical action (by a helpful human) turns the coil in the magnetic field produced by a strong horseshoe magnet. The faster he turns, the larger the current, the brighter the light. See this now in film loop FSU-20.

In an electric generator, as you saw, mechanical energy is converted into electrical energy by means of electromagnetic induction. An electric generator is just one of the many practical and important applications of this effect, so it was necessary to develop some quantitative way of understanding and predicting these phenomena. So we're going to work with two useful concepts--induced EMF, and magnetic flux. The induced EMF we've already discussed. You remember that when a circuit is moved with a given velocity relative to a given magnetic field, the same EMF is induced, regardless of the amount of resistance in the circuit. Thus we see that this electromagnetic induction is like putting a battery in the circuit, like supplying an electric field.

In all these demonstrations the important thing seems to be that we change the amount of magnetic field passing through the loop, by moving the field or the loop. Let's try to write down these relations in a quantitative way. Let's consider our loop, which has an area A, in a field of magnetic field strength B. At this point we'll give a name to the total amount of field passing through this area. We'll call this the magnetic flux, and use the symbol ϕ to denote flux. See Figure 2. (Van Name uses "f" instead of ϕ for flux, but ϕ is the more usual symbol.)

How is $\emptyset$ related to B and A? As a first guess, we might say it could be defined simply at the project of B and A. But clearly $\emptyset$ will be different for different positions of the loop, depending on what angle the loop makes with B. If the loops' area A is perpendicular to B, there is a maximum amount of flux, AB through the loop; but if the loop is parallel to B, there is no flux through the loop at all. For loop positions in between these two extremes, the flux through the locp is some fractional part of the maximum. So we will take as a measure of the amount of field passing through the loop the flux

Eqn. 1 $\qquad \emptyset = A\ B_1$

where B_1 is that component of B which is perpendicular to A. As is pointed out in your text, flux is measured in webers, A in $(\text{meters})^2$ and B_1 in webers/m^2.

This amount is passing through the area A which is bounded by a loop in a magnetic field. You may sometimes hear a physicist call this the amount of flux "threading" the loop; this emphasizes that it is the area bounded by the wire loop that is of importance, not just the area of the actual piece of wire. But the galvanometer deflections, and the lit-up light bulb, indicating the presence of an induced current, occurred only when there was movementor change of some kind. The quantity of interest here really is the rate of change of magnetic flux. If the flux through area A is $\emptyset$ at a certain time, t_1, and a little later at a time, t_2, it is $\emptyset_2$, the change in flux is $(\emptyset_2-\emptyset_1)$, which can be written $\Delta\emptyset$, and this change occurred in a time interval Δt, which is simply (t_2-t_1). It turns out that the amount of emf induced in the wire loop is given by:

Eqn. 2 $\qquad \text{emf} = \dfrac{\Delta\emptyset}{\Delta t}$

We'll put off discussing that minus sign for a few minutes. In how many ways could $\emptyset$ be changed to get a $\Delta\emptyset$? Remember $\emptyset = AB$. One way we have used is to move a magnet in and out of the loop. This causes B to change from nearly zero to a maximum when the magnet is in the loop. In this case $\Delta\emptyset = (\Delta B_1)A$, where B_1 is the total change in B_1. Notice that the faster this is one, the smaller is the time t, and the larger the emf induced. This fits in with the observed results of the demonstrations. Another system we've used is to move the loop through a magnetic field. Here, again, the B through the loop rises from nearly zero to a maximum inducing an emf in the wire which is proportional to the speed; when we withdraw the loop, B drops from its maximum down to almost zero, so we have a change $(-\Delta B_1)$ and the induced emf is in the opposite direction.

Now we'd like to demonstrate some other ways of changing $\emptyset$. For convenience in these demonstrations, instead of the field of a permanent bar magnet, we will use the magnetic field created by an electric current flowing in a coil of many turns of wire. In this way, we can more nearly change the strength of the magnetic field, simply by changing the amount of current flowing in the coil. This coil is connected to a battery and to a meter which shows the amount of current in the coil. Let us call this coil I.

In film loop FSU-15, you will see two coils of wire which have a common axis. The second coil of wire in these experiments contains no battery. It is connected only to the galvanometer, to show any currents which may be induced in the coil. We'll call this coil II.

But now we see that we can change ϕ without *moving* the coil or the field. We can simply change the *size* of B, and the resulting ΔB should cause an induced emf in coil II. An easy way to change the size of B, since it is a magnetic field produced by a coil of wire, is simply to turn the current on and off in the field-producing coil (coil I). Remember the two coils are alike except that one is connected to a battery and a switch, so that by closing and opening the switch, I can turn on and off the current in that coil I. This creates a magnetic field in the vicinity of the coil which changes from zero to the full value B and back to zero as the switch is closed and opened. The second coil is close enough to the first to be in the magnetic field created by the first coil, so we would expect a current to be induced in the second coil when we close the switch in the first. Let us check this by connecting the galvanometer to the second loop. All right, we'll close the switch on the first loop, and sure enough, the galvanometer shows a deflection as induced current flows through the second coil. The switch remains closed, so a constant current flows in the first coil, and the galvanometer comes back to its zero position. Why? The current is still flowing in the first coil, and there is still a magnetic field present. But it is not *changing*, and it is the *change* in B that causes the induced current in the second coil. When the galvanometer stops swinging, we'll spoil this peaceful condition by opening the switch in the first coil, thereby cutting off the current in that coil and letting the magnetic field decrease to zero. The galvanometer immediately swings out again--but in the opposite direction this time, because the magnetic field is getting smaller instead of larger; the sign of B has been reversed. The coils are not connected to each other in any way, except by means of the magnetic field. (See Figure 4)

That is the first demonstration you'll see in film loop FSU-15, turning the current on and off in coil I, and observing the resulting current in coil II, as evidenced by the galvanometer deflection. After this, three more ways of changing the flux through coil II, and getting an induced current, are shown; first, by moving coil II away from coil I, out to where the magnetic field due to coil I is smaller. As coil II is moved away from, and closer to, coil I, galvanometer deflections in opposite directions are observed. Next coil II is swung out sideways to a region of smaller field strength; again, the galvanometer deflects. (We could, of course, have moved coil I instead; the flux through coil II would still change, and cause an induced current in coil II.)

Suppose we wanted to keep B constant in size and direction but change the area A. One easy way to do this physically is to turn the loop from a position in which its area is perpendicular to B to a position in which it is parallel to B (See Figure 4). You can see that in Figure 4 there is no magnetic flux through area bounded by the coil, so the effective area of the loop perpendicular to B is zero. When the area is perpendicular to B, its effective area is the full actual area, A. For positions between these two extremes, the effective area is some fractional part, or component, of the actual area A. In other words, by rotating the loop in this way in the magnetic field, we periodically change the effective area perpendicular to B from the full value A down to zero and back up to A. This is just what happens in a generator, as the large coils rotate. But now we have a more quantitative way of looking at what happens in the generator. Although the magnetic field itself doesn't change, and the actual area of the loop, or coil, does not change, there is continuous change in the effective area of the coil, by which we mean here the component of the area which is perpendicular to B. (Or the component of B which is ⊥ to A) This is the next demonstration in the film loop. Lastly, if we move the two coils together, so there is no change in their relative positions the flux "threading" coil II shouldn't change at all, so there should be no galvanometer deflection. See if this actually happens in the last demonstration in film loop FSU-15. Please view it now, then come back here.

You may have noticed that these demonstrations are really an exercise in finding different ways to produce an induced emf, which is equal to $\frac{\Delta\phi}{\Delta t}$, which in turn is equal to $\frac{\Delta(AB1)}{\Delta t}$

This is in your supplementary sheet, equation 3. Let's look at this equation for a minute.

Eqn. 3 $\quad$ induced emf $= \frac{-\Delta\phi}{\Delta t} = \frac{-\Delta(AB1)}{\Delta t}$

It tells you several important things; in fact, most of what you need to know about induced emf. First, to get an induced emf, you must somehow cause a change in ϕ, called $\Delta\phi$. It further tells you that the faster you make a given change $\Delta\phi$, the greater the emf, since the Δt in the denominator is smaller. Another interesting bit of information to be extracted from this equation is that $\Delta\phi$ may be caused either by a chance in area A or in B1.

Here's a question I'd like you to think about between lessons--can you figure out a way of rotating a loop in a constant magnetic field so that no current is induced in the loop?

There was another demonstration film loop we wanted to show you right here, but it's not ready yet. Maybe that won't break your heart; anyway, we can tell you about it. We want to carry one of the earlier demonstrations to a ridiculous extreme. Remember when we turned the current on and off in coil I and observed induced currents in coil II? Suppose instead of a switch and a battery, we connect an alternating current source into coil I; you know, ordinary household a.c. Now the current in coil A changes up and down sixty times a second, so any induced current will show up in coil II, also changing size and direction 60 times/second.

Now, suppose coil II consisted of only 1 turn of wire, and there was a small light bulb in the circuit instead of the galvanometer. The induced current would go through the wire and the light bulb, but might not be big enough to light the bulb. If more and more turns are gradually added to coil II (and this is what we would have liked to show in the film loop) then the flux will be changing through all those turns, and the induced emf through N turns will N times the emf through one turn. As the number of turns is increased, the light bulb gradually lights up. This is known as the transformer effect; it is based on having a circuit of many turns around an area of highly concentrated magnetic field, so that the effect of the changing flux is multiplied.

Lenz's Law

With the right hand rule, we could, in principle, figure out the direction of the induced current in these devices. We would then find that the induced current itself gives rise to a magnetic field. The flux due to this field must oppose the flux change that caused the induced emf in the first place. Otherwise, the induced current would set up flux which would further the original flux change, causing still further induced current and emf, etc., and continue to build up and up without any more energy being put into the system. This would violate the conservation of energy principle. This effect has been generalized by a Russian physicist named Lenz to a very convenient law, which saves us a lot of maneuvering with the right hand rule to figure the direction of induced currents. It simply states that the induced current is always in such a direction as to create a magnetic flux opposing the change being made. Another way of saying this is that nature is basically conservative, and tries to maintain the status quo. This opposition shows up in the minus sign in the relation: $\text{emf} = \frac{-\Delta \phi}{\Delta t}$.

For example, the film loop FSU-15 showed two similar coils on a common axis, one of which was connected to a battery with a switch. The other was connected to the galvanometer. When the switch was closed in the first coil, the current flowed and produced a magnetic field. This change in flux caused an induced current in the second coil, the direction being such as to produce a magnetic field of opposite direction to that produced by the first coil.

Film loop FSU-10 is another demonstration of Lenz's law. We're going to swing a metal plate on the end of a pendulum through the strong magnetic field produced by a horseshoe magnet. Such a pendulum experiences a force opposing its motion at all times. Why? As the metal plate swings into the field, the free electric charges in the metal experience a force and a current flows, creating a magnetic field opposing the one they are getting into. This effect is not large enough to completely cancel the original B. As the plate swings past the center point the plate passes through a maximum value of B and from then on B is decreasing. Now the induced currents in the metal are in a direction to create a magnetic field opposing this change in B. The induced currents set up in the metal plate cause it to heat up, as you could attest to if you could touch that plate. Where does the energy come from to supply that heat? It comes from the force exerted by gravity in pulling the pendulum down and through the magnetic field. Ultimately, of course, the energy was supplied by the man when he pulled the pendulum to one side, giving it potential energy. Soon the pendulum comes to a stop as its energy has all been dissipated in heat due to induced currents in the metal.

Maybe you doubt my reason for the pendulum stopping; maybe it would stop anyway--due to friction in the suspension, say. I think the second part of the demonstration will convince you. In place of the original metal plate, I'm going to use a cut-out version, for the purpose of breaking up all those little currents due to the free charges being pushed around as they move through the field. Incidentally, we call these "eddy currents". Now when we let this pendulum swing through the magnetic field, it does not stop. The eddy currents have been largely eliminated due to their pathways being cut.

Now, please see FSU-10, then come back here.

By now, you've seen so many induced current demonstrations that we may have induced a hypnotic state. Cheer up; we're about to go out with a bang--provided by the last demonstration--demon's rings, or jumping rings. Unfortunately there's no sound track on our film loops so it's up to you to provide the "Bang!" when these rings go crashing to the floor. Here's the script for the scene:

A metal ring, like an outsize bangle bracelet, is placed over the core protruding from a coil, not yet switched on. The purpose of the core is to "extend" the coil's magnetic field out to where we can use it for this experiment. The coil is connected to an a.c. electric outlet so that the magnetic field again is reversed automatically 60 times per second.

We start with the current in the coil switched off--no magnetic field--and place the brass ring over the core. Now, when we switch the current on, bang! The rings fly off the core. Why? The fluctuating magnetic flux from the coil causes induced current in the metal ring, which in turn produces a magnetic field opposing the change. But this magnetic field is not large enough to overcome the original field from the coil plugged into the electric outlet. There is another way in which the ring can react to oppose this changing magnetic flux--that is, to remove itself mechanically from the field! This it does with great haste when I switch on the current.

This shows that a force is pushing up on the ring, enough to overcome its weight. Let's increase the weight of a ring just enough to balance that upward force. Here's a ring that's been adjusted to the right weight. The up and down forces are now in balance when switch is turned on, and the result is a floating ring.

We've claimed that the upward force in this case is the result of the induced currents in the ring. If that's so, and we break up the path for these currents by cutting an opening in the ring, this upward force should no longer balance the force of gravity and the ring must fall. Next, we'll use such a ring with a cut across it; I'll switch on the current and attempt to "float" the ring as before, but it falls down. Or, if it starts at the bottom, it does not jump up. The eddy currents are no longer there.

All these demonstrations indicate that there is a close connection between magnetic fields and electric fields. Indeed, magnetism is really just another manifestation of electricity.

You'll remember that when we studied light, we avoided answering the question, what is the medium that vibrates? We are now in a position to answer, and will do so in the next lesson. Now please view FSU-30, then go to your terminal for a lecture quiz.

Lecture 25 - Electromagnetic Waves

In the last few lessons, we've learned something about electricity and magnetism, and the ways in which they are related to each other. We can summarize our results briefly as follows:

1) Moving electric charges produce magnetic fields.

2) Magnetic fields exert forces on moving electric charges.

3) Changing magnetic fields set up electric fields.

In a previous lecture, we had particularly stressed that magnetism was just another manifestation of electricity. In this lecture, we point out that light is simply another manifestation of electricity-magnetism. This may be surprising to you at first, since the connection between light and electricity and magnetism isn't at all obvious at a glance. So let's talk about it for a while.

Light is a pretty important subject; in fact, you'll remember we made it essentially the first real physics topic we took up in this course (after learning a few basic definitions and techniques). If you'll recall, we debated its nature -- did it act like a wave, or like a particle -- and on the basis of certain pieces of experimental evidence, we decided that it could best be described as a wave. At that time, perhaps, you thought about some other kinds of waves that you were more familiar with: water ripples in a pond; transverse waves traveling along a rope; sound waves passing through the air. And you may have wondered: what is this light wave which can propagate in a vacuum? What is it that "waves" if there is no medium for it to wave in?

At the time we studied light, we weren't in a position to answer this question because you didn't yet have enough information at your disposal, but now we can finally do so. We assert that a light wave consists of fluctuating electric and magnetic fields. These two fields "wave" at right angles to each other, and both are in a plane perpendicular to the direction or propagation. Hence light is a transverse wave. The wave as a whole is referred to as an electromagnetic wave; you'll find an illustration of one in figure 1 of your supplement.

Now, how does such a pulsating electromagnetic field come about? Well, it can be set up by the back-and-forth oscillation of charges on a straight conductor, or antenna. The changing magnetic field which is set up in this way will in turn automatically set up a changing electric field to accompany it. In turn, this changing electric field will set up a changing magnetic field, and so on, in a continuous process.

This self-regeneration of the electromagnetic field in a propagated wave was predicted by Maxwell in the 1860's. His theory showed that the speed of the waves given by and calculated from known electric and magnetic constants, was the same as that already known for the speed of light! In fact, since his theory allowed for an infinite range of frequencies and wavelengths, the wavelengths associated with visible light were included. It was concluded that light was not a separate area of physical phenomena, but was in fact merely a part of a vast electromagnetic "spectrum" which is now known to include radio-waves, microwaves, infra-red rays, ultra-violet rays, X-rays, the gamma rays associated with radioactive processes, and of course, the well-known visible spectrum ranging from red to violet. However, these various types of waves are thought of as distinct areas since they are normally produced and detected by different means.

Let's go back and look at the word spectrum. You probably think of it as referring to the spread of wavelengths your eye is sensitive to as a brilliant rainbow of colors occupying definite positions in relation to each other. If you have any familiarity with the electromagnetic spectrum, you might realize that this is a spectrum which encompasses all possible wavelengths, of which the visible region is but a very small part. The human eye is sensitive only to that portion of the spectrum which is called visible--in the wavelength region of approximately 4×10^{-7} meters to 7×10^{-7} meters. The region of greatest eye-sensitivity, incidentally, is ___________ for green light.

You probably have familiarity with some of the other parts of the spectrum whether you have thought about it or not. For example, sun lamps emit predominately "ultraviolet" rays which give you a tan. These rays lie on the violet side of the visible portion--at lower wavelengths and therefore higher energy. On the other hand, the familiar "heating lamp" used in various applications is a source mostly of infra-red rays. These rays lie just on the low energy, or longer wavelength side of the visible part of the spectrum next to the red.

One part of the electromagnetic-spectrum that you hear a lot about these days is the microwave region. You see microwave towers scattered about the country now as microwaves are being used more and more in our telephone and communications industry. The waves have wavelengths of a few cm. to a few meters and the region lies between infra-red and radio waves.

You're going to see a film loop which demonstrates microwaves. Notice the transmitting antenna and the receiving antenna which contains a light bulb to act as a means of seeing when waves are being received. The fluctuations of electric field in a microwave beam sets up a fluctuation current in the receiver and the bulb lights up. The position of the receiving rod is changed to show you the conditions for proper reception. Now, watch the film loop carefully. We hope you will now be better prepared on the subject of electromagnetic waves.

Well, this about wraps up our study of the classical aspects of electricity. So far, we've said a good deal about the microscopic effects produced on or by streams of moving electrons, but up to this point it hadn't been necessary to say much about the individual electrons themselves, outside of pointing out that each one carries a small charge. For the next topic which will be taken up, namely physics, it will be necessary to know some more about the electron as one of the fundamental building blocks of matter. One of the first things it is useful for us to know about the electron is its mass.

There are several ways in which the mass of an electron can be measured. One of them will be demonstrated in the film you are about to see. In this method, a beam of electrons is accelerated through a potential difference in a cathode ray tube which has been placed in a magnetic field. Since (as you learned in a previous lesson) moving charges in a field experience a deflecting force, the electron beam is deflected in a circular arc. If the radius of curvature of this arc is known, the velocity of an electron can be found. Then, by equating its kinetic energy with its known electrical potential energy, we can find the mass. Watch this film very closely. Although it will seem complicated to you, you will be able to see a practical application of many of the things you have learned previously about electricity, magnetism, and energy.

Some of the more important mathematical steps and calculations are summarized in your supplement sheet.

Now, before looking at the film, report to your terminal for a quiz on this lecture. Then ask the proctor for film 413, "Mass of the Electron and when you've finished seeing it, go back to your terminal once more.

Lecture 26 - Rutherford Atom

In the late 1800's, J. J. Thomson had established the existence of the electron as one of the fundamental building blocks of atoms and had demonstrated that it had a negative charge and a small mass. . . about 1/2000 that of the smallest whole atom. He assumed that the atom consisted of an extensive block of positive charge with electrons embedded throughout it. . . like tiny marbles stuck in putty. His model was given the picturesque name of "plum pudding" or "Raisin pudding" model. According to it, a piece of matter consisted of a continuous structure of the blobs of positive charge which accounted for practically all the mass of the material . . . since electrons had so small a mass.

Around 1910, Ernest Rutherford conducted some experiments which could not be explained in terms of Thomson's model. His experiments were made possible by the discovery of radioactivity some 12 years before . . . and . . . his own work which showed that some radioactive materials shot out positively charged particles with fast speeds . . . about 1/10 the speed of light. Rutherford found that these particles . . . we call them alpha particles . . . were about four times more massive than the hydrogen atom and about 8,000 times more massive than an electron.

What Rutherford did was allow a beam of these fast, massive alpha particles from a radioactive source . . . to shoot through a very thin gold foil. Screens of zinc sulphide were used to detect where the particles went after striking the gold. Zinc sulphide sends out light when struck by an alpha particle and a patient observer in a dark room can count alpha particles by counting the number of light pulses. By noting the way in which the alpha particles were scattered from the foil, Rutherford hoped to deduce what the foil "looked like" to the alpha particle beam. His results are shown in your supplement; study this graph. The angle, theta, equal to zero means that the alpha particle went straight . . . as if it struck nothing in going through the foil. Theta equal to 90 degrees means the incoming alpha particle struck something at an angle and came off sideways to the incoming beam direction. Theta equal 180 degrees means that the alpha particle was scattered backwards . . . exactly in the opposite direction to its incoming direction. It is important that a few--but only a very few--particles were observed to be scattered backwards--at 180 degrees.

On Thomson's plum pudding model--NO backward scattered particles are expected because neither the electron nor the positive blob had enough mass in the place where the alpha particle hit . . to bounce it backwards. Consideration of the conservation of energy and momentum show that an object will only bounce backwards to its original direction when it strikes a more massive object in a head-on collision.

Rutherford postulated a new atom model with the following features: First--massive positively charged centers (instead of a large blob) which we now call nuclei--spaced at great distances from each other. This was necessary to explain his scattering experiment.

Second--electrons orbiting about these nuclei--held in orbit by the electric force of attraction between positive and negative charges. This was needed to keep atoms--and all matter from collapsing into an exceedingly small space if the negative electrons and positive nuclei could come together.

To summarize: His model added up to a tiny (about 10^{-14}m in radius) positive nucleus containing all the positive charge and almost all the mass of the atom--about which negative electrons of negligible mass while in circular orbits of radius large compared with the size of the nucleus. Well, Rutherford's idea seemed to fit the experimental results . . . but soon . . . a most distrubing question popped up. An accelerating charged particle is known to emit radiation . . and as it emits . . it loses energy . . thus an electron would not maintain orbit and would crash into the nucleus in about 10^{-11} seconds.

Well, it's pretty clear that if atoms only held up for that length of time, there wouldn't be any atoms as we know them around for us to work with by now, or any scientists either, for that matter. If the fact that there are still quite a few atoms around isn't enough to convince us, we should be convinced by the atomic spectra of the elements. If an atom were to radiate in the way we've just described, we would expect its spectrum to be continuous--that is, one continuous blur of color beginning at violet and ending at red. But it doesn't, it emits a spectrum made up of a number of very sharp, distinct lines. A drawing of one such spectrum is shown on page 202 of your text; if it were in color, you would see that the lines are of different colors.

So physicists were stuck with a real problem. The atom exists; it is stable; it emits a line spectrum. Classical physics could not come up with a satisfying explanation, and things were at a kind of standstill until Neils Bohr came up with his famous interpretation. Among other things, he introduced the idea of only certain size orbits occurring in the atom. But we're going to keep you in suspense about that temporarily. Before going into Bohr's ideas in any kind of detail, it's necessary first to know something about certain other developments in physics which were going on at about the same time or a little earlier.

Let us recall a few facts about light. We remember from lessons 7,8, and 9 that certain properties of light such as reflection are consistent with both particle and wave models, while certain other properties like refraction, interference, and diffraction seem consistent only with a wave model. You may have thought then that the wave model of light seemed a lot more satisfactory but now we have some new phenomena to explain, and as you will see, the particle analogy again becomes useful.

Now, as an introduction to the next lesson, on "Photons," please view film number 418 after you have worked through the audio quiz on this lecture.

Lecture 27 - Photons and Matter Waves

Until the year 1900, observations of the behavior of light (and other radiation, such as heat) could be understood in terms of wave theory. A few years before Rutherford was performing his famous scattering experiments, other scientists were investigating and puzzling over radiation phenomena which could not be explained in terms of wave theory.

One of these men was Max Planck of the University of Berlin. Planck was interested in explaining the spectrum of colors or wavelengths of light which were radiated from a small hole in a well insulated, blackwalled enclosure which could be held at different temperatures. Such a device is called a "black body." Careful studies of this black body radiation revealed, among other things, that the spectrum was always the same for a particular temperature regardless of the material of which the black body was made. In the year 1900, Planck provided a theoretical interpretation of this spectrum. The details of his explanation are complicated and will not be described here, but it is important to note that a new revolutionary idea was essential to his explanation:

Planck assumed that light was emitted in "bundles" or "packets" each carrying an amount of energy, $\underline{hf}$ where $\underline{h}$ is a constant now called Planck's constant and $\underline{f}$ is the frequency of the light. The existence of the light packets was an interesting theoretical assumption but no one seemed too concerned over further consequences of this discovery.

Then, in 1905, Einstein seized upon Planck's idea and used it to explain another phenomenon, the photoelectric effect. This effect had been noted some 18 years earlier by Hertz during his research on electromagnetic waves. He noticed that ultraviolet light could expel negative charge from a piece of zinc metal. By 1900, other workers proved that it was the negative particles called electrons which were being ejected from the zinc.

Some interesting facts were uncovered about these photoelectrons; a) not just any frequency (or color) of light would eject electrons from a metal. In fact, no matter how strong or bright a light was used, if it had too low a frequency, NO photoelectrons were found. On the other hand, a weak or dim light source of higher frequency caused electrons to come from the metal. Making this higher frequency source stronger resulted in the ejection of more electrons at the same speed, while increasing the frequency resulted in greater speed of the photoelectrons. Intensity determined the number of electrons ejected, the frequency determined the speed of the ejected photoelectrons; b) the minimum frequency required varied from one target material to another. Ultraviolet light was necessary when copper was the target, whereas for potassium, both ultraviolet and visible light were effective.

Efforts to reconcile these observations with the wave theory were completely fruitless. A strong light is a very large amplitude wave and should be able to knock out electrons even though its frequency is low, but this does not occur in the photoelectric effect. The weakest light (smallest amplitude wave) of higher frequency can always eject electrons from the metal's surface. Also, on the wave theory, the speed of ejected electrons should be greater for strong light (large wave), but it was found to depend only on frequency. Thus, the wave theory of light failed to explain the photoelectric effect.

In 1905, Einstein was able to explain the observations not with a wave theory, but by using Planck's notion of light "packets." Briefly, his idea was this:

(1) Light exists in bundles or quanta, each one carrying a discrete amount of energy given by $E = hf$;

(2) Individually, quanta or packets of light interact with electrons to produce the photoelectric effect.

Now the observations can be explained! If the frequency of light is too low, each quantum has too little energy to eject an electron. Making the light strong results in more quanta with each one still too weak to eject an electron. Increasing the frequency of the light, however, gives more energy to each quantum so that it can strike an electron a sufficient blow to knock it from the metal. On this theory, the speed of the photoelectrons would depend upon the frequency and that is what was observed. Incidentally, it was this work for which Einstein received the Nobel Prize, not for his famous equation, $E = mc^2$.

In case you are wondering how big are these light quanta, the answer is -- not very! Planck's constant, h, has the value 6.62×10^{-34} joule seconds. Since the frequency of visible light is of the order of 10^{15} cycles/second, the energy of a typical quantum is of the order of 10^{-19} joules. This is indeed a small amount of energy by our usual standards, yet surprisingly, the human eye is sensitive enough to react to just a few quanta per second.

With this preparation we can return to the problem of the Rutherford atom. What keeps the atom stable (that is, from radiating continuously)? And, if it is stable, how can we account for the very definite line spectrum which it is known to emit?

Niels Bohr came up with an idea. He said: "Let us assume that an electron can occupy one of a number of possible orbits, and no others. As long as it occupies one of these, it has a tendency to stay there, and the atom is stable. But it can also jump from one of these so-called "permitted" orbits to another one. While it is in-between two of them, the atom is unstable, but it doesn't ever stay there for long. In fact, it is so anxious to always be in one of the permitted orbits that it won't even attempt a transition or jump to a higher energy orbit as they are called, unless it has exactly the right amount of energy provided by a light quantum (Bohr called them photons) of just the right size. Now things really begin to make sense! Imagine an electron spinning in what we will call the first orbit (the one closest to the nucleus). A photon whose energy, hf, happens to be just right strikes it, imparting energy to it. It at once jumps to a higher orbit which happens to be available. It's important to note that which orbit it jumped to depended upon the energy of the photon striking it. It could have been the 2nd, or the 3rd, or any one of many others, all depending upon hf.

Now, let's say that the electron has been there a while, doesn't care for the scenery, and decides it would rather be back where it started, or in some other orbit of lower energy. To get there, it must lose energy, and that energy must be of just such an hf as to correspond to one of the permitted transitions. So it emits a photon, and down it goes, to its new orbit. If we happen to have a spectrograph around at this time, we can get a good record of what has taken place in the form of a sharp line. This line was produced by the light energy of the emitted photon. If many transitions are taking place at the same time, then many distinct lines are recorded. They constitute a spectrum.

This, then, is what is happening. We now come to the very important question. What are the allowed orbits? How are we to decide what their sizes will be? And here is where Bohr made his revolutionary hypothesis. He assumed that only orbits of certain radii were found in nature. We will not discuss Bohr's original method of specifying these permitted orbits, but rather we'll use an idea which Louis de Broglie conceived some ten years later. Since we know that light, a wave phenomenon, also has a particle nature, why not, he said, assume that the electron, a particle, also has a wave nature? The wave length of an electron, was far too small to be detected experimentally which was why it had never been noticed before, but that did not mean that it didn't exist. He went on to describe a situation in which the electron could occupy any orbit the length of which was exactly equal to an integral number of its wavelengths. To demonstrate this, he used the analogy of standing waves. Before we go on, we'd better say a few words about standing waves.

Most of us have seen an example of this phenomena at one time or another. If you tie a rope firmly at one end and, holding the other end in your hand, flick your wrist in a quick motion,a wave pulse will be transmitted down the rope. When it reaches the end, it will be reflected back to your hand. Now, if you move your hand up and down continuously in just the right rhythm, you will arrive at a situation where a wave of the shape of the one illustrated in figure 71 (page 154) of your text is created. This is a standing wave; it may be thought of as the superposition of two traveling waves of exactly the same shape traveling in opposite directions. There are some stipulations as to the size of these waves, though. Notice that there is a node--that is, a point of zero amplitude at eigher end. Each "loop" is exactly half a wavelength long. Thus, the length of the rope must be n (wavelength) ; in other words, it must contain an integral number of half wavelengths.

Now we've been talking about standing waves produced on a rope with fixed ends. We could instead have closed the rope in upon itself to form a circle, with the standing waves still present. A little reflection will convince you that in order for the circle to close smoothly upon itself and still support standing waves, its circumference must be equal to an integral number of whole-wavelengths. If you don't see this at first, try drawing it until you are convinced.

In the de Broglie interpretation of the Bohr atom he assumed that the wave nature of the electron required that it occupy an orbit with a circumference equal to an integral number of the electron's wavelengths. Thus, we can say that a standing wave situation exists. However, we can't specifically say that the electron itself constitutes a standing wave, or sets up a standing wave made of any physical material. If this seems upsetting to you--and it does to many people--remember that this is just one of the paradoxical qualities of the wave-particle duality of nature. It is impossible to understand in terms of familiar, everyday experience. The important thing is that the model works. We will go into the Bohr atom in more detail in the next lecture. We'll conclude this one by saying a little bit more about de Broglie's ideas.

When a photon transfers energy, in a bundle hf, it transfers momentum as well, in a bundle $\frac{hf}{c} = \frac{h}{\lambda}$ = momentum. We can verify this experimentally by watching the motion of electrons after collision with photons in a cloud chamber. Note that the old relations, $p = mv$ and $E = \frac{mv^2}{2}$ which applied to slower particles do not apply here.

In 1923, de Broglie wondered if, since light, which had been thought to be a continuous wave, had also a particle nature, perhaps particles of matter had wavelike properties associated with them. Davisson and Germer, who showed that under certain conditions, a beam of electrons exhibits destructive interference, which is a property of waves. The wavelengths observed in this destructive interference were just those predicted by the de Broglie relation.

In our ordinary experience, things act like particles or like waves. Our experiments on the atomic level show us that our ordinary experience with Newton's particle mechanics is not an adequate guide. We really have no reason to expect that things as small as photons or electrons will behave like things which are large enough to see. When we try to explain these phenomena, we are forced by our limitations to try to make analogies with things we can see, but we should not be too disappointed if we need unfamiliar combinations of these analogies to properly describe the unfamiliar phenomena.

Before watching the next film, PSSC #419, think way back to the "double-slit" demonstration when we were studying light, earlier in the course. When you looked through the slits at a light source, you saw a pattern of light and dark bands, called an interference pattern. This was explained on the basis of the wave model. The width of the bands turned out to be a function of the wavelength of the light.

Now, I want you to imagine that the light source grows dimmer and dimmer. Still you see the light and dark bands, though they become harder and harder to distinguish. To help in the observation, you put a sensitive photomultiplier, a device you were introduced to in a previous film (#418), in place of your eye and read minima and maxima on a meter as the photomultiplier scans across the interference pattern. The whole system is enclosed in a box to keep out extraneous light.

Suppose you decide to go to the extreme of cutting light down so far that there is rarely more than one photon in the box at a time, so that there is no question of interference between two or more photons. The process by which this is achieved is described briefly in the PSSC film guide; if you happen to be among the ambitious and/or curious, you can look it up. What happens to the interference pattern in this situation? Does it suddenly disappear when the average number of photons in the box at a time drops below some critical value? How many photons do you need in the box together to observe interference? Physicists being what they are, had to find out. Now watch the experiment in the film and see whether your expectation was borne out. The film length is 13 minutes. Before watching the film, go to your terminal for a review on this lecture, then view film 419.

Lecture 28 - Bohr's Atom

In the last lecture, you were introduced to an idea which may have proved somewhat shocking. This was the wave particle duality concept for all matter as exemplified by the fact that to every piece of matter, a wavelength can be assigned. In this one, it is our purpose to sort of tie things together; to demonstrate in as simple a way as possible just how a wave particle situation may come about.

Let us return to the hydrogen spectrum which was introduced previously (and which is very important in physics as it keeps popping up here and there).

It was the mathematician Balmer and the spectroscopist Rydberg who originally found a neat formula for the frequencies of the lines appearing in the hydrogen spectrum on the basis of number theory and experimental observations. The formula they found was:

Equation 1 $$f_{in} = \frac{E_n - E_1}{h}$$ (h being Planck's constant)

where E_n is an energy measured in electron volts, and can be found from the relationship:

Equation 2 $$E_n = \frac{-13.6}{n^2} \quad , n = 1, 2, 3 \ldots .$$

In other words, the atom emits (and absorbs) light (energy) in discrete amounts.

Consider the following example: When an electron makes a transition from the second to the first orbit:

$$E_2 - E_1 = hf_{21}$$

from the third to the first orbit:

$$E_3 - E_1 = hf_{31}$$

or, the energy lost by the electron in going from a more energetic to a less energetic orbit is emitted as a photon of energy, hf. Notice, no energy is lost, but kinetic and potential energy of the electron are converted into a packet of electromagnetic energy or a photon. Furthermore the equation $E_2 - E_1 = hf_{21}$ predicts the frequency (or color in the case of visible light) of the emitted radiation.

You might ask if this is what happens when an electron moves from orbit 2 to orbit 1. What about the reverse process? Can an electron be induced to go the other way--from orbit 1, the innermost, to orbit 2, the next one out? As with some other things in nature, the process is reversible. But only the proper frequency of radiation or photon of just the right energy can induce the transition of the electron from orbit 1 to orbit 2. Its energy can be calculated from the same equation: $E_2 - E_1 = hf_{21}$. In this case, the photon is not emitted but absorbed. In the early 1900's, experiments showed that a given element would absorb the same frequencies which it emitted. This is the subject of the Franck-Hertz experiment which you will see in today's movie. Bohr's theory provided an interpretation which shows why it is so and added to man's comprehension of nature.

In Rydberg's and Balmer's formula, the number 13.6 fell out as a constant. It remained for Neils Bohr to give physical meaning to this number and to tie up a large number of "loose ends" that earlier physicists had left lying around into a workable model of the atom. This he did in 1913.

Bohr was aware of the trouble with Rutherford's planetary-type model. Briefly (as you may recall from a previous lesson), the problem is this: a moving charge is known to emit radiation (i.e., give up energy). Electrons of course are nothing other than moving charges. Thus, theoretically the electron moving in its orbit would continually give up its energy. As it did so, it would spiral inward eventually falling right into the nucleus. In other words, the atom would collapse--and this entire process would take only 10^{-11} seconds! Well, from the fact that there are still plenty of atoms around, including those that go to make up atomic scientists, we conclude that this doesn't happen (fortunately!).

But in that case what are the happy circumstances that cause the atom to be stable? Bohr tackled this question and concluded that there must be some orbits which the atom can occupy without giving off energy and thus be stable. Such orbits could be designated by the so-called "quantum numbers," $n = 1, 2 \ldots.$ This approach, of course, contradicted the classical theory but did explain the facts. Bohr knew about photons, waves, and the wave particle duality of light. Perhaps then (he decided) one should postulate a wave particle duality for all matter including electrons--not just light.

Why do this? Well, because this suggested a way in which the stable orbits of an electron could be described. He assumed that the electron could be thought of as essentially a standing wave.

At this point, let's recall what we learned in the last lesson about standing waves--that a standing wave can exist in a medium which forms a closed circle whose circumference is equal to an integral number of wavelengths. This may be hard for you to see at first (it gives us trouble, too, sometimes!), but there is a drawing in your supplement.

What Bohr assumed was that the allowed orbits were the ones whose circumferences would contain a number of the matter-wavelengths that the electron would have while it was in its wave state.

In other words, the circumference 2 pi $r_n = n L_n$ $(2\pi r_n = n \lambda_n)$. where r_n was the radius of the orbit described by the quantum number n_1 and L_n the wavelength the electron had when it was in that orbit.

This is as far as Bohr went. It remained for de Broglie to give an actual value to the wavelengths. You'll recall from the last lesson that he postulated that for a matter wave,

$$L = h/p,$$

but he did this considerably later. Actually the correct equation is

$$L_n = h/p_n \quad .$$

We can now add the subscript (quantum number) whereas we didn't have sufficient knowledge at our disposal before.

Regarding quantum numbers: $n = 1$ signifies the innermost orbit, $n = 2$, the second orbit, and so on.

In the equation of Rydberg and Balmer which we mentioned earlier,

$E_n = \frac{-13.6}{n^2}$, the "constant" 13.6 turns out to be

none other than the energy in electron volts required to remove the electron in a hydrogen atom from the innermost ($n = 1$) Bohr orbit or, in other words, to ionize the hydrogen atom. Bohr was able to show this.

How many possible orbits are there? You may wonder. A mathematical way of getting an answer to this question is shown in pages 3 and 4 of your supplement. You should go through the derivation there carefully because it will show that we already have the information necessary to find the radius of all the possible orbits, the velocities of the electron in each of these orbits, and the energies associated with these orbits. However, you don't have to go over this derivation right now or even before the lecture quiz. The only fact that you need in order to understand the rest of the lecture is that each allowed orbit must have a circumference equal to an integral number times the wavelength of the electron in that orbit. Thus, the answer to the question is that there are an infinite number of possible orbits because the only restriction placed on the size of an orbit is that its circumference contains an integral number of wavelengths. Then the circumference of an allowed orbit can be increased by one wavelength at a time endlessly. Thus, there are an endless number of orbits of larger and larger radius.

Though this is true, it may be misleading in terms of what is observed in the field of atomic physics. Let's turn our attention away from radii and direct it toward the energies of the electron in the allowed orbits. While radii increase in size indefinitely, the energy of each larger orbit increases slowly and approaches a maximum value no matter how large the radius becomes. This means that if an electron in orbit were struck by another fast moving electron, so that it received a considerable amount of kinetic energy in the collision then it would do one of two things:

(a) occupy a higher energy orbit if it received the correct energy to do this. We call this an excited atom,

or

(b) If its energy were greater than that of allowed orbit, it would travel outward indefinitely, leaving the nucleus behind, moving too fast to occupy an orbit. We call this an ionized atom.

In space age terms, we would say that this electron had a velocity greater than the escape velocity. In this discussion we have been considering a single, isolated atom.

In summary, the atomic theory of Bohr which was published in 1913 drew on the previous work on:

planetary motion by Newton;
electric charge by Coulomb;
the nature of atoms by Rutherford;
the nature of radiation by Planck and Einstein.

He assembled these with his new idea that only certain orbits occur in nature and he put together one of the most significant theories to explain the nature of matter. Though his original theory was refined and later replaced with a more sophisticated theory, the original breakthrough of Bohr remains a milestone in the history of science.

Introduction to Film 421 -- (Franck-Hertz experiment)

The significance of this experiment is that it demonstrates that a substance absorbs energy packets of only certain sizes and these energy values correspond to certain lines in the absorption spectrum of the substance. Furthermore, the substance emits energy also only in these same size packets--as shown by the fact that the emission spectrum has lines of the frequencies corresponding to those energy packets, as related by the formula: $E = hf$. The substance used in this experiment is mercury; the abosrbed energy comes from the kinetic energy of electrons which collide with the mercury atoms.

This experiment was an important verification of Bohr's theory of quantitized orbits. But the experimenters did not even know of Bohr's theory at the time--as Dr. Franck tells you in his talk at the end of the movie. Incidentally, Dr. Franck visited the FSU campus just a few years ago as an honored guest giving students and faculty a rare opportunity to meet one of the pioneers of modern physics.

The film involves considerable explanation of the techniques used, but don't lose track of the main idea as outlined above. It is the quantitization of energy absorption of the mercury vapor (4.9 electron-volts is a quantity of energy). This amount of energy corresponds to a frequency, f, given by $f = \frac{4.9 \text{ electron volts}}{h}$; and this in turn corresponds to a wavelength $\lambda = \frac{c}{f}$, where c is the speed of light. This calculates out to be

$\lambda = 2537 \times 10^{-10}$ meters, the same as the experimentally observed line in the emission and absorption spectrum of mercury. This correspondence marked a big step forward in man's understanding of the atom.

Now please go back to your terminal for a lecture quiz, then view film 421, the Franck-Hertz experiment.

Lecture 29 - Modern Physics IV

Today, in our last lesson, we're going to talk a little about modern physics in general. Of course, this is too extensive a subject, and requires too much mathematics for us to go into it in much detail in this particular course, so we'll just discuss it qualitatively so as to give you an idea about some of the main points. Let's first review briefly something of what we've previously learned. Early in the century, spectroscopists had discovered that under certain conditions, atoms which have been excited, that is, have had energy added to them, emit sharp flashes of light in the form of a line spectrum.

A great milestone of modern physics occurred in 1913 when Niels Bohr provided a theoretical interpretation of the spectrum of one particular kind of atom-hydrogen. He used hydrogen because it is the simplest atom. However, his ideas, with some modification, can be applied to all atoms. Briefly, then:

1) There exist certain "stationary states" in which the atom is stable and does not radiate energy.

2) In passing from one such stationary state to another, the atom emits (or absorbs) radiation whose frequency is given by

$$F_{21} = \frac{E_2 - E_1}{h}$$

These "stationary states" correspond to the "allowed" orbits for an electron; a transition from one such state to another occurs when an electron moves from one orbit to another. We used a standing wave interpretation to describe the allowed orbits. Bohr's interpretation was found to predict the behavior of nature. The correctness of his ideas opened the way for a new mathematical theory to describe all of modern physics. This theory is called quantum mechanics.

Quantum mechanics asserts the following points:

1) The propagation (motion) of all matter can be described in terms of the mathematical theory of wave propagation. A de Broglie wavelength of $L = \frac{h}{p}$ can be assigned to any matter particle, and the energy in the "waves" is thought of as coming in bundles of $E = hf$. The matter particle can be a sub-atomic particle or it can be a macroscopic object. There is no restriction on its size.

2) Examine the de Broglie wavelength for a particle $L = \frac{h}{mv}$ you can see that at comparable speeds, the larger the particles'

mass, the smaller its wavelength. Also, matter waves in general have for smaller wavelengths than ordinary light waves. Since the effects of waves can only be observed with slits whose widths are of the same order of magnitude or the wavelengths of the waves under investigation, it is fairly difficult to see interference and diffraction effects even with particles as small as electrons, protons, and so on, and it's impossible to see them as macroscopic objects whose wavelengths are very small indeed.

3) All matter interacts with other matter by giving up its' energy in bundles (quanta); that is, it interacts as particles. For macroscopic objects, the energy bundles are so small and so many are given up at once, that with our limited senses, geared to everyday experience, changes in energy appear continuous and we observe no quantum jumps. The smaller the system we have, the more pronounced and important do quantum effects become, and we really only begin to observe them on the atomic level, such as in the case of electron orbital transitions. Even the behavior of moving electrons in a wire does not require quantum mechanics to describe it; current is a macroscopic phenomenon. If I were to try to summarize the essence of all we've covered in one sentence--and, admittedly, one sentence will hardly do justice to such a topic--my choice of a sentence would be: "Light (or matter) propogates as a wave and interacts as a particle." If you see that, you're on your way to at least beginning to accept the wave-particle duality of all of nature.

4) Since quantum theory works so nicely on the atomic level, you might well expect that it would work on the sub-atomic level, and it does. By "sub-atomic" we refer to the nucleus--that heavy core around which the electrons orbit--and its components.

You already know that the nucleus is positively charged. It is made up of heavy particles of unit positive charge called protons, and uncharged, or neutral, particles similar to protons in size and mass, called neutrons. Like electrons, these particles reside in distinct energy levels, and because these nuclear levels are so much farther apart than electronic levels, quantum effects are even more dramatically shown in the nucleus; for example, by the emission of higher energy electromagnetic radiation, like gamma rays. Nuclear forces--that is, the forces between the various constituents of the nucleus--are enormous. It is these forces which are involved when energy is unleashed in atomic and hydrogen bombs and other nuclear weapons, giving us something to worry about. This concludes our study of modern physics.

There! Now, you're free--except for your final, of course. Good luck. We hope you've gotten something out of this course, and have enjoyed it as much as we've enjoyed presenting it to you. Please go to your terminal after this lecture for a short review. Thank you for your attention.

APPENDIX F

HOMEWORK PROBLEMS

APPENDIX F.

HOMEWORK PROBLEMS

Physics 107 - Set I

1. a. In 1959 the population of the United States was about 176,000,000. Express this number in powers-of-ten notation. What is the order of this magnitude?

   b. Express as a power of ten the budget of the United States for a year when it is 71 billion dollars.

2. Using powers-of-ten notation, find the following:

   a. 0.00418×39.7 b. $\frac{6000}{.012}$ c. $\frac{.703 \times 0.14}{280,000}$

3. Suppose that there are 1.7×10^8 people living in the United States and that 7.5×10^6 of these people live in New York City. How many live in the rest of the country?

4. If your height and all your other dimensions were doubled, by what factor would

   a. your weight increase?

   b. the strength of your leg bones increase?

5. A man follows this route: From his house he travels four blocks east, three blocks north, three blocks east, six blocks south, three blocks west, three blocks south, two blocks east, two blocks south, eight blocks west, six blocks north, and two blocks east. How far and in what direction will he be from home?

6. a. By making a scale drawing with a ruler, find the result of adding a vector 2 cm. east to one 3 cm. northwest.

b. Find the result of adding a vector 8 cm. east to one 12 cm. northwest.

c. Compare the results of parts (a) and (b), and state a theorem about adding a pair of vectors which are multiples of another pair. Can you prove the theorem in general?

7. The index of refraction of carbon disulfide is about 1.63. What should the speed of light be in this liquid, according to the particle model of light?

8. Sound waves in air usually travel at about 330 meters per second. Audible sounds have a frequency range of about 30 to 15,000 cycles per second. What is the range of wave lengths of these sound waves?

9. A force of 5 newtons gives a mass m_1 an acceleration of 8 meters/second^2, and a mass m_2 an acceleration of 24 meters/second^2. What acceleration would it give the two when they are fastened together?

10. Find the applied force required to accelerate a 450-kilogram rocket from a standing start to a velocity of 60 meters/second along a 100-meter horizontal track. The retarding force of friction is 93 newtons.

HOMEWORK PROBLEMS

Physics 107 - Set I

Solutions

1a. $\boxed{1.76 \times 10^8}$

order of magnitude $\boxed{10^8}$

1b. $71 \times 10^9 = \boxed{7.1 \times 10^{10} \text{ dollars}}$

2a. $(.00418 \times 39.7) = 4.18 \times 10^{-3} \times 3.97 \times 10^{1}$

$= 16.6 \times 10^{-2} = \boxed{1.66 \times 10^{-1}}$

2b. $\frac{6000}{.012} = \frac{6.0 \times 10^3}{1.2 \times 10^{-2}} = \boxed{5.0 \times 10^5}$

2c. $\frac{.703 \times 0.14}{280,000} = \frac{7.03 \times 10^{-1} \times 1.4 \times 10^{-1}}{2.8 \times 10^5} = \frac{(7.03)\ (1.4)\ (10^{-7})}{2.8} =$

$\boxed{3.5 \times 10^{-7}}$

3. $(1.7 \times 10^8) - (7.5 \times 10^6)$

$= (1.700 \times 10^8) - (.075 \times 10^8)$

$= (1.700 - .075) \times 10^8$

$= \boxed{1.625 \times 10^8}$

4a. $2^3 = \boxed{8}$

4b. $2^2 = \boxed{4}$

5. Total north = 3 + 6   9

Total south = 6 + 3 + 2   11

net 2 blocks south

Total east = 4 + 3 + 2 + 2 = 11

Total west = 3 + 8 = 11

net zero east-west

So net displacement is 2 blocks south

HOMEWORK PROBLEMS

Physics 107 - Set I

Solutions--Continued

6a.

6b.

6c. (b) is simply a "scaled-up" drawing of (a). The two vectors in (b) are four times as large as in (a), and the resultant is four times as large also. Let $\vec{R} = \vec{A} + \vec{B}$. In vector algebra, this can be written: $4\vec{A} + 4\vec{B} = 4\ (\vec{A} + \vec{B})$ or, more generally, $n\vec{A} + n\vec{B} = n\ (\vec{A} + \vec{B}) = n\vec{R}$, where n is any number.

HOMEWORK PROBLEMS

Physics 107 - Set I

Solutions--Continued

7. Particle model predicts that light travels faster in a denser medium, proportional to index of refraction, so

$$\text{speed (in the dense liquid)} = n\ (\text{speed in air})$$
$$= 1.63\ (3.00 \times 10^{8}\ \text{m/sec.})$$
$$= \boxed{4.89 \times 10^{8}\ \text{m/sec.}}$$

8. wave length = speed/frequency or $L = v/f$

$v = 330$ m/sec.

F or f = 30 cycles/sec., $L = \dfrac{330\ \text{m/sec.}}{30\ \text{cycles/sec.}} = 11$ meters

F or f = 15,000 cycles/sec., $L = \dfrac{330\ \text{m/sec.}}{150 \times 10^{2}\ \text{cycle/sec.}} = 2.2 \times 10^{-2}$ meters

So the range of wave lengths is from $\boxed{.022\ \text{m. to } 11\ \text{m.}}$

9. $F = 5$ nt $\quad a_1 = 8\ \text{m/sec.}^2$ so $m_1 = \dfrac{F}{a_1} = \dfrac{5}{8}$ kg

$$a_2 = 24\ \text{m/sec.}^2 \text{ so } m_2 = \frac{F}{a_2} = \frac{5}{24}\ \text{kg}$$

$$(m_1 + m_2) = m_{TOTAL} = \frac{15 + 5}{24} = \frac{20}{24} = \frac{5}{6}\ \text{kg}$$

$$\text{So } a = \frac{F}{m_{TOTAL}} = \frac{5\ \text{nt}}{5/6\ \text{kg}} = \boxed{6\ \text{m/sec.}^2}$$

HOMEWORK PROBLEMS

Physics 107 - Set I

Solutions--Continued

10. $F_{friction} = 93$ nt. $\Delta v = 60$ m/sec. $k = 450$ kg

$d = 100$ m

Net force $F = ma = (450 \text{ kg})(a)$

To find $a = \dfrac{\Delta v}{\Delta t} = \dfrac{60 \text{ m/sec.}}{\Delta t}$

To find $\Delta t = \dfrac{d}{v_{average}} \quad \dfrac{100 \text{ m}}{v_{average}}$

$$v_{average} = \frac{v_{initial} + v_{final}}{2} = \frac{0 + 60 \text{ m/sec.}}{2} = 30 \text{ m/sec.}$$

$$\text{so} \quad t = \frac{100 \text{ m}}{30 \text{ m/sec.}} = \frac{10}{3} \text{ sec.}$$

$$a = \frac{60 \text{ m/sec.}}{10/3 \text{ sec.}} = 18 \text{ m/sec.}^2$$

$$F_{net} = (450 \text{ kg})(18 \text{ m/sec.}^2) = 8100 \text{ nt}$$

Applied force must be larger than this net force by an amount large enough to overcome force of friction, so

$$\text{Applied force} = F_{net} + F_{friction} = (8100 + 93) \text{ nt}$$

$$= 8193 \text{ nt}$$

HOMEWORK PROBLEMS

Physics 107 - Set II

1. How great is the impulse exerted by a 3.00-newton force for 6.00 second?

2. What happens to the velocity of an object when an impulse of 2.00 newton-second is applied to it? Suppose this impulse is applied

   a. to a 6.00-kilogram object

   b. to a 3.00-kilogram object

3. A skier with a mass of 75 kilograms is moving on level ground at a constant speed of 10 meters/second. Through some miscalculation, he finds himself brought to a stop in a snowbank during a Δt of 1.5 seconds.

   a. What impulse did the snow apply to the skier?

   b. What was the average force exerted by the snowbank to produce this change of speed?

4. A force of 10.0 newtons acts on a 2.00-kilogram roller skate initially at rest on a frictionless table. The skate travels 3.00 meters while the force acts.

   a. How much work is done?

   b. How much energy is transferred to the skate?

   c. What is the final speed of the skate?

5. a. Describe the steps you would follow to charge an electroscope positively by induction.

   b. Using labeled sketches, describe the movement of negative electric particles during the charging process.

6. Two electrified objects A and B are separated by 0.03 meters, and repel each other with a force of 4.0×10^{-5} newtons.

a. If we move body A an additional 0.03 meters away, what is the electric force now?

b. Does it make any difference which body we move? Explain.

7 a. How much energy is carried by an "average" photon of visible light with wave length of about 5,000 angstroms? How much momentum? ($h = 6.625 \times 10^{-34}$ joule seconds; $c = 3 \times 10^{8}$ meters per second.)

b. Estimate the number of photons of visible light emitted per second from a 100-watt light bulb emitting 1 per cent of its power in the visible region. (1 watt = 1 joule per second)

8. a. What is the wave length of X rays whose photons each carry 40,000 electron volts of energy? (1 electron volt = 1.6×10^{-19} joules)

b. About what energy electrons have a de Broglie wave length equal to that of 40,000-volt X rays? (Give your answer in electron volts.) (mass of electron = 9.11×10^{-31} kilogram)

c. What energy baseballs? (mass of baseball = 0.14 kilograms)

d. What is the wave length of a baseball moving at 10 meters per second?

HOMEWORK PROBLEMS

Physics 107 - Set II

Solutions

1. Impulse - $F\,\Delta t = (3.00\ nt.)\ (6.00\ sec.) = 18.0\ nt\text{-}sec$

2. Change in momentum = impulse

$$m\,\Delta v = 2.00\ nt\text{-}sec$$

$$\Delta v = \frac{2.00\ nt\text{-}sec}{m}$$

Since $1^{nt} = \frac{1\ kg\ m}{s\ sec^2}$, 1 nt-sec = 1 kgm/sec

(a) m = 6.00 kg

$$\Delta v = \frac{2.00\ nt\text{-}sec}{6.00\ kg} = \frac{1}{3}\ m/sec$$

(b) m = 3.00 kg

$$\Delta v = \frac{2.00\ nt\text{-}sec}{3.00\ kg} = \frac{2}{3}\ m/sec$$

3a. Impulse = change in momentum = $m\,\Delta v = (75\ kg)\ (10\ \frac{m}{sec}) = \underline{750\ \frac{kg\text{-}m}{sec}}$

3b. Average force = F

Impulse = F t

$$750\ \frac{kg\text{-}m}{sec} = F\ (1.5\ sec)$$

$$F = \frac{750}{1.5}\ \frac{kg\text{-}m}{sec^2} = 500\ neutons$$

4. m = 2.00 kg. x = 3.00 meters $f_x = 10.0$ nt

initial velocity = 0

(a) Work = $(F_x)\ (x) = (10.0\ nt)\ (3.00) = 30.0$ joules

(b) Energy transferred = work done = 30.0 joules

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(c) Final speed = v   kinetic energy = K.E.

$$K.E. = \frac{mv^2}{2}$$

$$30.0 \text{ joules} = \frac{(2.00 \text{ kg})(v^2)}{2}$$

$$v^2 = 30.0 \text{ m}^2/\text{sec}^2$$

$$v = (30.0)^{\frac{1}{2}} \text{ m/sec}$$

5a. (1) Bring a negatively charged body near the electroscope (not touching)

(2) "Ground" the electroscope

(3) Remove the "ground" connection

(4) Remove the negatively charged body

(1)

(2)

(3)

(4)

6. $F = K \frac{Q_A Q_B}{d^2}$ $F = 4.0 \times 10^{-5}$ nt
$d = 0.03$ m

(a) If we double d, d^2 becomes four times as large; since

$F \propto \frac{1}{d^2}$, F becomes one-fourth

its original value.

So $F = \frac{1}{4}(4.0 \times 10^{-5} \text{ nt}) = \boxed{1.0 \times 10^{-5} \text{ nt}}$

(b) No. The force depends only on the amount of charge on the two bodies, and the separation.

7. (a) $L = 5 \times 10^{3}$ Angstroms $= 5 \times 10^{-7}$ meters

(1 Angstrom $= 10^{-10}$ m)

$h = 6.625 \times 10^{-34}$ joule - sec

$c = 3 \times 10^{8}$ m/sec   frequency $f - c/L$

$$\text{Energy } E = h\,f = h\left(\frac{C}{L}\right)$$

$$= \frac{(6.625 \times 10^{-34}\ \text{joule - s}\cancel{e}\text{c})\ (3 \times 10^{8}\ \cancel{m}/\text{s}\cancel{e}\text{c})}{(5 \times 10^{-7}\ \cancel{m})}$$

$$= 3.98 \times 10^{-19}\ \text{joules}$$

$$\text{Momentum } p = \frac{h}{L} = \frac{(6.625 \times 10^{-34}\ \text{joule - sec})}{5 \times 10^{-7}\ \cancel{m})} = 1.32 \times 10^{-27}\ \frac{\text{kg-m}}{\text{sec}}$$

(b) 1% of 100 watts $= \left(\frac{1}{100}\right)$ (100 watts) = 1 watt = 1 joule/sec

From problem 7(a), energy per photon $E = 3.98 \times 10^{-19}$ joules

So, the number of photons per second is

$$\frac{1\ \text{joule/sec}}{3.98 \times 10^{-19}\ \text{joules/photon}} = 2.5 \times 10^{18}\ \text{photons/sec}$$

8. (a) $E = (4.0 \times 10^{4}$ electron volts$)\ (1.6 \times 10^{-19}$ joules/electron volt)

$= 6.4 \times 10^{-15}$ joules   (per photon)

f = frequency   L = wave length   p = momentum

c = speed of light $= 3.0 \times 10^{8}$ m/sec

$L = \frac{c}{f}$ (for any wave) so $f = \frac{C}{L}$

$$E = hf = h\left(\frac{C}{L}\right)$$

$$\text{or, } L = \frac{hc}{E} = \frac{(6.625 \times 10^{-34}\ \text{jo}\cancel{u}\text{le-s}\cancel{e}\text{c})\ (3.0 \times 10^{8}\ \text{m/sec})}{6.4 \times 10^{-15}\ \text{joules}}$$

$L = 3.1 \times 10^{-11}$ m

(b) $L = 3.1 \times 10^{-11}$ meters $m = 9.11 \times 10^{-31}$ kg. $E = ?$

de Broglie: $L = \frac{h}{p} = \frac{h}{mv}$; $mv = h/L$; $v = \frac{h}{mL}$

$$\text{so } v = \frac{6.625 \times 10^{-34} \text{ joule-sec}}{(3.1 \times 10^{-11} \text{ m})\ (9.11 \times 10^{-31} \text{ kg.})} = 2.3 \times 10^{7} \text{ m/sec}$$

$$\text{Energy } E = \tfrac{1}{2}\, mv^2 = \tfrac{1}{2}\, (9.11 \times 10^{-31} \text{ kg.})\ (2.3 \times 10^{7} \text{ m/sec})^2$$

$$E = (9.11)\ (5.4)\ (10^{-31})\ (10^{14}) = 2.5 \times 10^{-16} \text{ joules}$$

$$= 2500 \times 10^{-19} \text{ joules}$$

$$= 1500 \text{ electron volts}$$

(c) Same as (b) except $m = .14$ kg instead of 9.11×10^{-31} kg

$$v = \frac{6.625 \times 10^{-34} \text{ joule-sec}}{(3.1 \times 10^{-11} \text{ m})\ (.14 \text{ kg})} = 1.5 \times 10^{-22} \text{ m/sec}$$

$$E = \tfrac{1}{2}\, mv^2 = \tfrac{1}{2}\, (.14)\ (1.5 \times 10^{-22})^2\ \frac{\text{kg m}^2}{\text{su}^2} = 1.6 \times 10^{-45} \text{ joules}$$

$$= 1.0 \times 10^{-26} \text{ electron volts}$$

An alternate method: (a little algebra before calculating is used to reduce the amount of arithmetic):

$$E = \tfrac{1}{2}\, mv^2 = \tfrac{1}{2}\, (mv)\ (v) = \tfrac{1}{2}\, (mv)\ \left(\frac{mv}{m} \right)$$

But $mv = p$ (momentum)

$$\text{So } E = \frac{p^2}{2m}$$

from de Broglie hypothesis, $p = \frac{h}{L}$

$$\text{So } E = \frac{h^2}{2\ m\ L^2}$$

$$= \frac{(6.625 \times 10^{-34} \text{ joule-sec})^2}{2(.14 \text{ kg})\ (3.1 \times 10^{-11} \text{ m})^2} = 1.6 \times 10^{-45} \text{ joules} = 1.0 \times 10^{-26} \text{ electron-volts}$$

Another method: From equation above, $E = \frac{h^2}{2mL^2}$, you can see that since h is a constant, and L is the same as in 8b the energy E compared to that in question 8b must be related by inverse ratio of the masses:

$$\frac{E_{BASEBALL}}{E_{ELECTRON}} = \frac{m_{ELECTRON}}{m_{BASEBALL}} = \frac{9.11 \times 10^{-31}}{.14}$$

We know $E_{electron}$ = 1500 electron volts so

$$E_{baseball} = (1500 \text{ electron volts}) \frac{(9.11 \times 10^{-31})}{.14}$$

$$= \frac{(1.5)\ (9.11)\ (10^{3})\ (10^{-31})}{(.14)} = 1.0 \times 10^{-26} \text{ electron volts}$$

(d) Baseball $m = .14$ kg $L = ?$ $v = 10$ m/sec.

de Broglie $L = \frac{h}{p} = \frac{h}{mv} = \frac{6.625 \times 10^{-34} \text{ joule-sec}}{(.14 \text{ kg})\ (10 \text{ m/sec})}$

$L = 4.7 \times 10^{-34}$ meters

notice much smaller than wave length of visible light, which is of the order of 10^{-7} meters

STUDENT ATTITUDE TOWARD COMPUTER-ASSISTED INSTRUCTION

This is not a test of information; therefore, there is no one "right" answer to a question. We are interested in your opinion on each of the statements below. Your opinions will be strictly confidential. Do not hesitate to put down exactly how you feel about each item. We are seeking information, not compliments; please be frank.

NAME____ DATE____________________

NAME OF COURSE____

CIRCLE THE RESPONSE THAT MOST NEARLY REPRESENTS YOUR REACTION TO EACH OF THE STATEMENTS BELOW:

1. While taking Computer-Assisted Instruction I felt challenged to do my best work.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

2. The material presented to me by Computer-Assisted Instruction caused me to feel that no one really cared whether I learned or not.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

3. The method by which I was told whether I had given a right or wrong answer became monotonous.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

4. I was concerned that I might not be understanding the material.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

5. I was not concerned when I missed a question because no one was watching me anyway.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

6. While taking Computer-Assisted Instruction I felt isolated and alone.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only occasionally	Never

7. While taking Computer-Assisted Instruction I felt as if someone were engaged in conversation with me.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only occasionally	Never

8. The responses to my answers seemed appropriate.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only occasionally	Never

9. I felt uncertain as to my performance in the programmed course relative to the performance of others.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only Occasionally	Never

10. I found myself just trying to get through the material rather than trying to learn.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only Occasionally	Never

11. I knew whether my answer was correct or not before I was told.

:	:	:	:	:
Quite often	Often	Occasionally	Seldom	Very seldom

12. I guessed at the answers to questions.

:	:	:	:	:
Quite often	Often	Occasionally	Seldom	Very seldom

13. In a situation where I am trying to learn something, it is important to me to know where I stand relative to others.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

14. I was encouraged by the responses given to my answers of questions.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

15. As a result of having studied some material by Computer-Assisted Instruction, I am interested in trying to find out more about the subject matter.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

16. In view of the time allowed for learning, I felt too much material was presented.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only occasionally	Never

17. I was more involved in running the machine than in understanding the material.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only occasionally	Never

18. I felt I could work at my own pace with Computer-Assisted Instruction.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

19. Computer-Assisted Instruction makes the learning too mechanical.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

20. I felt as if I had a private tutor while on Computer-Assisted Instruction.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

21. I was aware of efforts to suit the material specifically to me.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

22. I found it difficult to concentrate on the course material because of the hardware.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only occasionally	Never

23. The Computer-Assisted Instruction situation made me feel quite tense:

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

24. Questions were asked which I felt were not relevant to the material presented.

:	:	:	:	:
All the time	Most of the time	Some of the time	Only occasionally	Never

25. Computer-Assisted Instruction is an inefficient use of the student's time.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

26. I put in answers knowing they were wrong in order to get information from the machine.

:	:	:	:	:
Quite often	Often	Occasionally	Seldom	Very seldom

27. Concerning the course material I took by Computer-Assisted Instruction, my feeling toward the material before I came to Computer-Assisted Instruction was:

:	:	:	:	:
Very favorable	Favorable	Indifferent	Unfavorable	Very favorable

28. Concerning the course material I took by Computer-Assisted Instruction, my feeling toward the material after I had been on Computer-Assisted Instruction is:

:	:	:	:	:
Very favorable	Favorable	Indifferent	Unfavorable	Very favorable

29. I was given answers but still did not understand the questions.

:	:	:	:	:
Quite often	Often	Occasionally	Seldom	Very seldom

30. While on Computer-Assisted Instruction I encountered mechanical malfunctions.

:	:	:	:	:
Very often	Often	Occasionally	Seldom	Very Seldom

31. Computer-Assisted Instruction made it possible for me to learn quickly.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

32. I felt frustrated by the Computer-Assisted Instruction situation.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

33. The responses to my answers seemed to take into account the difficulty of the question.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

34. I could have learned more if I hadn't felt pushed.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

35. The Computer-Assisted Instruction approach is inflexible.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

36. Even otherwise interesting material would be boring when presented by Computer-Assisted Instruction.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

37. In view of the effort I put into it, I was satisfied with what I learned while taking Computer-Assisted Instruction.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

38. In view of the amount I learned, I would say Computer-Assisted Instruction is superior to traditional instruction.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

39. With a course such as I took by Computer-Assisted Instruction, I would prefer Computer-Assisted Instruction to traditional instruction.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

40. I am not in favor of Computer-Assisted Instruction because it is just another step toward depersonalized instruction.

:	:	:	:	:
Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree

THIS SPACE IS PROVIDED FOR ANY COMMENTS YOU CARE TO MAKE ABOUT COMPUTER-ASSISTED INSTRUCTION.

KEY TO STUDENT ATTITUDE TOWARD COMPUTER-ASSISTED INSTRUCTION

Question	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
1	1	8	6	6	
2	1 1	17	2	1	
3	5	8	4	2	2
4	1	2	2	14	2
5	4	12		5	

Question	All the time	Most of the time	Some of the time	Only occasionally	Never
6		3	1	8	9
7	2	5	5	6	3
8	2	16	3		
9	3	3	5	7	3
10		5	10	6	

Question	Quite often	Often	Occasionally	Seldom	Very Seldom
11	5	10	6		
12		2	15	3	1

Question	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
13	2	12	2	5	
14		1	6	12	1
15		7	5	7	1

KEY TO STUDENT ATTITUDE TOWARD COMPUTER-ASSISTED INSTRUCTION--Continued

Question	All the time	Most of the time	Some of the time	Only occasionally	Never
16	1	1	5	7	6
17			1	7	11

Question	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
18	2	2	1	9	7
19	4	16		1	
20	2	6	5	6	1
21	1	5	8	7	

Question	All the time	Most of the time	Some of the time	Only occasionally	Never
22			3	8	10

Question	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
23	7	13		1	

Question	All the time	Most of the time	Some of the time	Only occasionally	Never
24			6	10	5

Question	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
25	11	7	2	1	

KEY TO STUDENT ATTITUDE TOWARD COMPUTER-ASSISTED INSTRUCTION--Continued

Question	Quite often	Often	Occasionally	Seldom	Very seldom
26	2	4	9	4	2

Question	Very favorable	Favorable	Indifferent	Unfavorable	Very unfavorable
27	2	3	6	8	2
28	2	8	7	4	

Question	Quite often	Often	Occasionally	Seldom	Very seldom
29		1	14	3	3

Question	Quite often	Often	Occasionally	Seldom	Very seldom
30	1	5	11	2	3

Question	Strongly disagree	Disagree	Uncertain	Agree	Strongly Agree
31			7	14	1
32	2	15	3	1	
33		2	2	17	
34	3	10	1	6	1
35	3	11	3	4	
36	11	7	2	1	
37		1	1	13	6
38	1	4	9	4	3
39	1	3	3	10	4
40	7	13		1	

APPENDIX G

PSSC FILM DESCRIPTIONS

APPENDIX G

Film No. 104

MEASURING SHORT DISTANCES

This film demonstrates techniques used to measure distances as small as 10^{-8} cm. It should be used with Section 3-3 of the PSSC text. Also see Laboratory 1-3 and Section 7-11.

Summary:

Dr. Montgomery uses optical microscopes to measure the sizes of various objects from 10^{-2} cm to $\approx 8 \times 10^{-5}$cm. Although bacteria are seen, their structure, about 10^{-5}cm, cannot be distinguished because of the resolution limit of the optical microscope. Using an electron microscope, the structure of bacteria is clearly visible and the ability to measure small distances to the resolution limit of the electron microscope - about the size of molecules, $\approx 10^{-7}$ cms. The layers of the molecules in a platinum phthalocyanide crystal are visible when a thin slice of the crystal is placed in an electron microscope, although at this magnification the contrast is poor.

The field emission electron microscope is discussed and demonstrated by Professor Muller of Pennsylvania State University. Compared to the electron microscope the contrast is improved, but the resolution is still not good enough to see individual atoms. The field emission ion microscope using helium atoms instead of electrons is shown to have sufficient resolution to view individual atoms - indeed, the atoms on the tip of the tungsten needle are seen.

Film No. 106

CHANGE OF SCALE

This film investigates the different effects produced as the scale of objects is changed. It should be used during Section 404 of the PSSC text.

Summary:

Professor Williams uses several examples to illustrate that when the dimensions of an object are changed, although its geometric relationships are not altered, its physical characteristics are often strongly modified.

A change in the scale of an object changes the strength-to-weight ratio. This effect is dramatized by comparing the diameter of ropes required to suspend a 500-kg safe and a 0.5-kg scale model.

Evidence of this dependence of strength-to-weight ratio on the scaling factor is found widely in nature; for example, the ability of small insects to move many times their weight. The proper scaling of dinosaurs is contrasted with the impossibility of large monsters as depicted by Hollywood movies.

The physical effects of scaling arising from the surface to volume ratio are illustrated with the hummingbird and the shrew, where a relatively large food input is necessary to maintain a constant body temperature.

Demonstrations are shown in which observations on scale models are interpreted using our knowledge of physics in order to predict the behavior of the normal size object; for example, the rolling of a ship in a rough sea.

Film No. 113

CRYSTALS

This film demonstrates the nature of crystal and describes how they are formed and why they are shaped as they are. It can be used during Section 8-14 through 16 of the PSSC text.

Summary:

Mr. Holden shows many different types of crystals, grown in the laboratory or found in nature. Through a micrscope, an alum crystal is seen growing out of a solution. Crystals of salol also are viewed through the microscope as they grow from the cooling melted material. Two ideas are emphasized: crystals are made of many small units, atoms or molecules, all alike; and these units are arranged in a regular array. Evidence for these ideas is presented throughout the films.

The fact that crystals grow natural plane faces peculiar to various substances is clearly illustrated. Mr. Holden shows the characteristic angles that can be formed between the natural faces of similar crystals by using pennies and small cubes to represent atoms or molecules.

Cleavage is offered as further evidence for believing that atoms are arranged in crystals in a regular array. Crystals of mica, nickel sulfate, and sodium nitrate are shown to cleave in certain directions only.

The fact that a particular kind of order is characteristic of a particular atom or molecule is shown when a solution of salol is seeded with alum crystals and nothing happens; when the solution is also seeded with salol crystals, the salol crystals grow but the alum is unaffected.

Film No. 201

INTRODUCTION TO OPTICS

The aim of this film is to introduce the student to some of the more important aspects of the behavior of light; to those experimental observations which support the idea that light propagates in straight lines, and to various ways in which the direction of propagation may be changed.

It is recommended for showing at the conclusion of Chapter 11 of the PSSC Physics text. Reference should be made to Sections 11-3, 11-6, 11-7, 12-1, 13-1, 13-7, 19-9 of the PSSC text.

Summary:

The sharpness of the shadow of an opaque object illuminated by a small source is presented as the basic evidence for the rectilinear propagation of light. The fuzziness of shadows cast by objects illuminated by large light sources is demonstrated and explained. It is then shown that even with a very small source, close examination of the shadow - especially near the edges - discloses the phenomenon of diffraction. Thus the statement that light travels in straight lines is one of limited validity.

The change of direction of propagation of light is demonstrated by scattering from smoke particles, by specular reflection, and by refraction. Reflection from a thin soap film is shown to demonstrate interference - not referred to by name - and the phenomenon of total internal reflection is also shown and discussed.

Film No. 203

SPEED OF LIGHT

This film demonstrates techniques for measuring the speed of light in air and in water over relatively short distances. It can be shown with Section 15-7 of the PSSC physics text.

Summary:

An experimental measurement of the speed of light in air is made by measuring the time it takes the light to travel a known distance. The experiment is performed on a playground so that the total distance the light travels (with the aid of a reflecting mirror) is about 300 meters. A pulsed light source (spark gap) is used, with an oscilloscope as the timing device.

A second experiment, utilizing a very fast rotating mirror, compares the speed of light in air to that in water. This demonstration is done in the laboratory.

Film No. 204

SIMPLE WAVES

This film demonstrates experimentally some of the properties of the straight-line motion of wave pulses that are pictured and discussed in the

PSSC text. Reference is to be made to Chapter 16 of the text and Laboratory II-7, 8.

Summary:

A series of demonstrations is performed with the slinky, a brass spring, a rubber tube and a torsion-bar wave machine. It is shown that the velocity of a wave pulse depends upon the nature of the medium in which the pulse moves. Specifically, pulses will generally have different speeds in different media, but a constant speed in the same uniform medium. Even in the same material, changing the mechanical state (for example, tightening up on the slinky) will cause a change in speed of the wave pulse.

The torsion-bar wave machine is used to obtain transverse wave pulses traveling slow enough for easy observation. By generating different pulses it is shown that the velocity of a pulse does not depend on its size or shape. The phenomenon of partial transmission and partial reflection at the boundary of two different media is demonstrated.

Film No. 301

FORCES

This film aims to set the stage for the study of Newtonian mechanics by discussing the forces found in nature and showing appropriate experiments to illustrate their salient properties. Its main purpose is to present to the students a preview of things to come. Consequently, comprehensive discussion of the material at this time is to be avoided.

It is recommended as an introduction to the material in the PSSC text, Part III.

Summary:

The principal points made in this film are:

(a) Intuitive concepts of forces and their effects are familiar to all, and serve the student better at the beginning of mechanics than attempts to use formal definitions. Various effects of forces are demonstrated.

(b) "Contact" forces are so called because of the roughness of everyday observation; but closer examination - ultimately on an atomic scale - will disclose that such forces really push and pull at a distance.

(c) All forces of nature can be understood in terms of three basic types, gravitational, electric (or electromagnetic), and nuclear.

(d) The universality of gravitational attraction is indicated by performing the Cavendish experiment. This experiment illustrates the relative weakness of gravitational forces compared to electrical forces.

Film No. 302

INERTIA

This film (together with the following one on Inertial Mass) leads into the study of dynamics by providing some experimental basis for the generalizations which comprise Newton's law of motion.

The film Inertia relates to Sections 20-1, 2, 3, 4 of the PSSC physics text. Inertial Mass relates primarily to Sections 20-5, 6. Both films relate to Laboratory III-2, 3, 4.

Summary:

Professor Purcell begins with an experimental investigation of the simplest practicable situation - the motion of a body on a nearly frictionless surface with no applied force (Dry Ice pucks on a smooth table). Galileo's principle of inertia is suggested from the observations.

Next, a single constant force is applied to a body initially at rest. Analysis of the ensuing motion shows that such a force produces uniform acceleration of the body in a straight line.

A third experiment demonstrates the effect of twice the original force upon the motion of a single body acted on by two forces of different directions is in the direction of their vector sum.

The question of the acceleration of different bodies acted on by the same force is deferred until the next film, Inertial Mass.

Film No. 303

INERTIAL MASS

This film presents the second half of a series of experiments leading to Newton's law of motion which began with the film Inertia. The focal point of Inertial Mass is the study of the dynamical behavior of different objects under the action of the same force.

The film Inertia relates to Sections 20-1, 2, 3, 4 of the PSSC physics text. Inertial Mass relates to Sections 20-5, 6. Both films relate to Laboratory III-2, 3, 4.

Summary:

First Dr. Purcell experimentally establishes the inertia of the low-friction disc used in the Inertia film as a standard. Next, a body consisting of two such identical discs fastened together is accelerated by the same force as in the first experiment. The fact that the acceleration is halved, assuming additivity of inertia, suggests that the acceleration under a given force is inversely proportional to the inertia of the body. From this one is led to a method for comparing inertias; their ratio is the inverse ratio of accelerations under a given force.

The third experiment shows that very dissimilar objects may have the same inertia. The fourth experiment uses the inference previously made to establish the inertia of a book relative to that of the standard; that is, to "measure" the inertia of the book.

A reference is made to the close relationship between gravitational mass and inertia.

Finally, the relation $a \; \frac{F}{m_i}$ is inferred from the experiments performed in this film and the previous film, Inertia.

Film No. 305

DEFLECTING FORCES

Deflecting Forces examines the relation between force and acceleration for motion in a curved path.

It is recommended for use just after the study of Section 21-5 of the PSSC physics text.

Other references are: Sections 6-5, 6, 7 of the PSSC physics text, Laboratory III-6, and the related materials in the Teacher's Guide.

Summary:

Projectile motion suggests that the motion of a body in a curve requires a net force which is not in the direction of the motion. That component of the force perpendicular to the velocity is defined as a deflecting force.

Professor Frank demonstrates, using low-friction apparatus, that a pure deflecting force changes the direction but not the speed of a body; the larger the force, the sharper the change in direction. It is argued that such a force having constant magnitude will produce uniform circular motion. This is shown experimentally.

To examine the applicability of Newton's law for this case, the acceleration

$$a = \frac{4\pi^2 R}{T^2} = \frac{v^2}{R}$$

is derived, and the direction of $\vec{v}$ and $\vec{a}$ are established relative to the rotating position vector R. Using the same force on the same body that Professor Purcell used in the film Inertia, Professor Frank finds experimentally the same magnitude of the acceleration for circular motion as was found for the straight-line motion; this shows that the inertial mass of the body is the same for both motions, and suggests that Newton's law is a vector law, with mass a scalar quantity.

In conclusions, the point is made that if one assumes that $\vec{F} = m\vec{a}$ holds for all motions, one may use observed accelerations to uncover the existence of forces in nature and to measure them.

Film No. 307

FRAMES OF REFERENCE

This film displays experimentally the changes in the appearance of motion as viewed from frames of reference moving relative to one another. Demonstrations of motions relative to inertial and accelerated frames of reference serve to introduce the idea of "fictitious" forces.

The great virtue of this film lies in the visual presentation of motions from various reference frames. These motions are generally hard to visualize for the beginning student.

It is recommended for showing with Sections 21-9, 10, 11 of the PSSC physics text. See also Sections 6-2,7.

Summary:

The motion of a freely falling body is observed from two frames of reference, one fixed to the earth and the other moving relative to the first with constant velocity. Although the observed paths are different, the acceleration of the body is the same in both observations, It is inferred that all reference frames moving with constant velocity relative to one another are equivalent; i.e., if Newton's law of motion is valid in any one of them, it is valid in all of them. Another demonstration illustrates the addition of velocity.

Motions in a reference frame accelerating in a straight line relative to an earth frame and in a rotating reference frame are demonstrated. It is shown that Newton's law of motion does not hold in such accelerated frames. To use Newton's law in such non-inertial frames one must introduce "fictitious" forces which compensate for the effect of the acceleration of the frame of reference. The idea of centrifugal force is then introduced as the fictitious force acting on a body at rest in a rotating frame of reference.

It is pointed out that an earth-fixed frame of reference, which is a non-inertial frame because of the rotation of the earth about its axis and about the sun, serves very nearly as an inertial frame because the accelerations involved are relatively small.

Reference is made to the Foucault pendulum as experimental evidence of the earth's rotation about its axis.

Film No. 311

ENERGY AND WORK

This film presents experimental evidence that the kinetic energy gained by an object is measured by the work done by the net force acting on it.

It pertains to Chapters 24 and 25 of the PSSC text, and should be shown when the students are at the middle or end of Chapter 25. Reference should also be made to Laboratory III-11, 12.

Summary:

The kinetic energy gained by a 10-kg ball falling from rest a distance of 3 meters is calculated from the measured average speed of fall for the last 15 cm of the path. This kinetic energy is then compared with the work done on the ball by the constant gravitational attraction of the earth during this motion. Emphasis is placed on the calculation of work as the area under a force-distance curve.

In a second experiment, a cart is pulled from rest by a force which varies in a complex manner with the position of the cart. Its gain of kinetic energy as it moves a definite distance is obtained as in the previous experiment. The force is produced by a mechanical device which plots a force-distance curve automatically. The work done on the cart is obtained by computing the area (counting squares) under the experimental force-distance curve (see Figure 24-5 of the PSSC text), and is compared with the measured gain of kinetic energy of the cart.

A "Rube Goldberg" device is shown which demonstrates a number of processes in which energy is transformed.

Finally, the rise in temperature of a spike driven into a log by the 10-kg falling ball is observed and indicates the transformation of mechanical energy into thermal energy.

Film No. 313

CONSERVATION OF ENERGY

This film illustrates the principle of energy conservation for the energy transformations in an operating power plant. It also shows that the basic laws of physics operate outside the classroom and the laboratory--and on a comparatively huge scale.

It can be shown any time during the latter part of Chapter 26 in the PSSC text.

Summary:

At the electric power plant at Salem, Massachusetts, the energy transformations from the burning of coal to the generation of electrical energy are followed. These transformations comprise the change of stored chemical energy in the coal to the thermal energy of the steam, to the mechanical energy of the turbine and finally to the electrical energy from the generator.

It is shown how by measurement and calculation for each step of the process one accounts for all the energy fed into the system. A check of about 1 per cent is obtained.

Film No: 402.

COULOMB'S LAW

Experiments are performed which demonstrate that the force between two charges is proportional to the product of the charges and varies inversely as the square of the distance between them.

It relates to Sections 28-1 through 28-3 of the PSSC physics text, and Laboratory IV-3.

Summary:

The qualitative characteristics of electric forces between charges are demonstrated. The student is reminded that he is already familiar with the inverse-square law of light and of gravitation, and it is suggested that the electric force also obeys the same inverse-square law.

To measure the dependence of electric force on distance, a charged sphere is mounted on a beam balance. The force of repulsion by a second similarly charged sphere is measured by a calibrated spring. The distance between the charged spheres is doubled, then tripled, and the force is seen to decrease to one-fourth, then to one-ninth, of the original value. The charge on each sphere is then halved by charge-sharing, and the resultant force decreases to one-fourth the initial value. Thus, Coulomb's Law $F \sim \frac{q_1 q_2}{r^2}$ is established.

Professor Rogers argues that if this inverse-square relationship is correct, then the geometry of a charged metallic hollow sphere is such that the sum of the forces due to all the charges on this sphere add up to give no net force on a test charge at any point inside this sphere. This effect is demonstrated.

A further experiment with a huge wire cage shows that this effect is independent of the shape of the conducting enclosure.

Film No. 404

MILLIKAN EXPERIMENT

A version of the classic Millikan experiment is performed in this film showing that charge comes in multiples of a natural unit. It is strongly recommended that this film be shown to supplement the concepts of Sections 28-4 and 28-5 of the PSSC text.

Summary:

Professor Friedman introduces the experimental apparatus and provides a running commentary which describes and interprets the experiment as it is performed by Dr. Redfield. In this experiment a small charged plastic sphere of known mass is introduced between two horizontal, parallel metal plates, and its motion is observed with the help of a microscope. The plates are charged by batteries and the number of batteries is adjusted until the charged sphere is motionless. In this situation the electric forces on the sphere is equal and opposite to the gravitational force on the sphere. By comparing the distance the sphere falls in five seconds with no electric force acting on it to the distance it falls with the above electric force reversed, pulling downward with the gravitational force, it is established that the terminal speed of the sphere in air is proportional to the net force acting on it.

The charge on the balanced sphere is altered with X rays; the electrical force on the sphere is no longer balanced by the gravitational force. The speed of the sphere is measured under these conditions. The speed provides a measure of the change of electric force and, consequently, of the change of charge on the sphere. This whole process is repeated several times.

The measured speeds fall into definite groups separated by a common speed difference equal to the smallest speed measured. These data indicate that the addition or loss of charge on the sphere occurs only in whole-number multiples of a natural unit.

Film No. 409

ELEMENTARY CHARGES AND TRANSFER OF KINETIC ENERGY

In this film experiments are performed to investigate the amount of kinetic energy transferred to an elementary charge as it is accelerated through a vacuum diode.

It is recommended that the film be used with Section 29-5 of the PSSC text.

Summary:

Charges boiled off from a hot filament are accelerated through a known distance by the electric force per elementary charge established in the film Millikan Experiment. Using this force and distance, Professor Friedman predicts the kinetic energy of each elementary charge as it hits a copper anode.

The charges dissipate their kinetic energy as heat when they hit the anode, and the rise in temperature of the anode, indicated by a thermocouple, is a measure of the energy transfer. To predict the total energy transferred to the anode per second the kinetic energy per charge is multiplied by the number of charges per second flowing through the circuit as measured by an ammeter. Running the experiment for a time interval such that the kinetic energy transfer is predicted to be 11 joules, the temperature rise of the copper plate caused a 24-division deflection of the meter connected to the thermocouple.

To determine that the deflection of the thermocouple meter corresponds to the dissipation of the 11 joules of energy, the temperature rise of an identical copper plate is measured when 11 joules of mechanical energy from a falling weight is transferred by friction to the plate.

In addition it is established from this experiment that the force exerted by fixed charges on a moving charge is independent of the speed of the moving charge. Also, this experiment shows that the unit of charge determined in the Millikan experiment is the same as the unit determined in a Faraday electrolysis experiment.

Film No. 413

MASS OF THE ELECTRON

In this film the mass of the electron is determined from its motion in a cathode ray tube placed in the magnetic field produced by two long, parallel wires.

Although this film and the next one, Electrons in a Uniform Magnetic Field, both make this measurement, the techniques used are somewhat different. We would recommend that you become familiar with both films so that you can choose the one which best fits your needs.

This film and the next one were made for use during the last half of Chapter 30 of the PSSC text. If possible, use after the students do Laboratory IV-9, Also see Laboratory IV-10.

Summary:

Electrons are accelerated through a potential difference V in a cathode ray tube. The cathode ray tube is mounted midway between two parallel bundles of wires carrying current in opposite directions, which establish a fairly uniform magnetic field B perpendicular to the electron beam. The electron beam is deflected in a circular arc causing the fluorescent spot on the tube face to move. Professor Rogers determines the radius of this arc by fitting the shadow of a disk to the measured deflection and original direction of the electron beam.

The kinetic energy transferred to each electron is calculated: $aV = 1/2\ mv^2$. The magnetic field B is computed from the geometry of the setup and the current flowing through the wires.

Using the measured radius of curvature and these computed values of the kinetic energy and the magnetic field, the velocity and mass of the electron are determined.

Film No. 418

PHOTONS

In this film an experiment is performed to demonstrate the particle nature of light. The film relates to Section 33-1 of the PSSC text.

Summary:

Professor King describes the apparatus he will use to demonstrate that light exhibits a particle-like behavior. A photomultiplier detects the very weak light used in the experiment. The operation of this device is outlined and the amplification is determined to be about 10^6 by measuring the output current and photoelectron current going into the first stage of the photomultiplier. The photomultiplier is connected to an oscilloscope, and pulses are seen on the oscilloscope trace. He shows that the pulses are due to the weak light shining on the photomultiplier, but that some pulses are due to background noise. To reduce this thermal background, the photomultiplier is cooled by a mixture of Dry Ice and alcohol.

The difference between the continuous wave model and the particle (photon) model for the transport of light energy is illustrated by an analogy to the delivery of milk. He shows that if the milk is to be delivered at the rate of one quart every ten seconds this can be achieved in either of two ways: (1) a pipe in which milk flows continuously at the uniform rate of one quart every ten seconds, or (2) a conveyor belt on which quart cartons of milk are randomly positioned so that on the average one quart of milk is delivered every ten seconds.

In the first case then, there is a consistent 10-second delay before one quart of milk is delivered. However, in the second case, although on the average one quart (packaged) arrives every ten seconds, there is no consistent delay between the arrival of successive quarts; and thus some arrive at intervals of less than 10 seconds. It is this idea, of looking for the arrival of packages in less than the average time interval that Professor King uses to find out whether light energy comes in packages (photons).

A beam of light shines on the photomultiplier through a hole in a disc. The light intensity is reduced with filters until the output current of the photomultiplier is only 3×10^{-10} amperes, implying that the photoelectron current is 3×10^{-16} amperes. This is equivalent to an average of one electron from the photocathode every $\frac{1}{2000}$ of a second. The photomultiplier output is displayed on the oscilloscope and, with the disc spinning at a constant rate, it is determined that the light shines on the photomultiplier for $\frac{1}{5000}$ of a second during each revolution. From the analogy using the flow of milk it is argued that a continuous transport of light energy would require $\frac{1}{2000}$ of a second between pulses from a photoelectron; whereas a particle model would imply that at any instant during the $\frac{1}{5000}$-second interval one might see a pulse from a photoelectron, with the average rate still one pulse every $\frac{1}{2000}$ of a second. The pulses are seen to arrive randomly during the $\frac{1}{5000}$-second interval implying the particle nature of light.

Film No. 419

INTERFERENCE OF PHOTONS

In this film the wave and particle nature of light are exhibited in one experiment in which an interference pattern is examined with a photomultiplier.

It is recommended that this film be used only after viewing the film Photons. The film relates to the subject matter in Section 33-3 of the PSSC text.

Summary:

Professor King describes the apparatus, which consists of an 8-foot-long box containing a weak light source. The light passes through a double slit, forming an interference pattern which is displayed visually. A photomultiplier connected to a sensitive ammeter is made to scan the pattern. The interference maxima and minima are clearly reflected in the meter readings. When the photomultiplier is connected to both an oscilloscope and a loudspeaker, the pulses seen on the oscilloscope screen correspond to the crackling of the loudspeaker. The pulse rate is seen to increase and decrease at the respective positions of the interference maxima and minima.

At a maximum of the interference pattern, the photomultiplier output current is measured to be 10^{-9} amp. Because the multiplier amplification is 10^{6}, this corresponds to an input current of 10^{-15} amp or about 10^{4} electrons per second. Professor King points out that, on the average, only one electron is ejected for every 10^{3} photons incident on the photocathode. Thus, a current of 10^{4} electrons per second corresponds to about 10^{7} photons per second incident on the photocathode.

In 10^{-7} seconds a photon travels about 100 feet. Therefore, it is argued that there is rarely more than one photon in the 8-foot-long apparatus. It is concluded that the interference pattern must be characteristic of individual photons, instead of an interaction between two or more photons.

Film No. 421

THE FRANCK-HERTZ EXPERIMENT

The aim of the film is to show the existence of discrete energy states of atoms. The classical Franck-Hertz experiment is performed, which establishes that the smallest energy that an electron can impart to an atom of mercury in an inelastic collision is 4.9 electron volts.

This film should be used with Sections 34-1 and 34-2 of the PSSC text.

Summary:

Professor Youtz points out that the light emitted by excited mercury atoms appears in the form of line spectra. Since mercury atoms (or any other kind) can lose only discrete amounts of energy - proportional to the frequency of their spectral lines - one might predict that these atoms can only gain discrete amounts of energy. This should be true whether this energy is supplied by photons, as in the absorption of light, or by any other means. It is noted that this hypothesis was originally tested in 1914 by James Franck and Gustav Hertz, who studied the energy transferred in inelastic collisions between electrons and mercury atoms. Professor Youtz then describes the apparatus he will use to repeat that experiment. The process of energy transfer by inelastic collisions, which lies at the heart of the experiment, is illustrated with the help of a mechanical model.

In a specially designed tube (see Figure 1), electrons are accelerated through mercury vapor and are detected by an ammeter in the anode circuit. Professor Youtz shows that with very little mercury vapor in the tube the current rises steadily as the accelerating voltage is increased. If the density of the mercury vapor is increased, he predicts a steady rise in anode current until the energy of the electrons reaches the minimum value for an inelastic collision to occur. At this point the current should decrease as the accelerating voltage is increased.

A pen recording of the anode current vs. the accelerating voltage shows the current rising and falling at regularly spaced intervals of 4.9 volts.

From an examination of the data it is concluded that 4.9 electron volts is the smallest amount of energy which can be absorbed by a mercury atom. It is calculated that this is the same amount of energy that is lost by a mercury atom when it emits a photon in the 2537 Å spectral line. This experiment implies that the mercury atom can exist only in states of discrete rather than continuous energies.

In an epilogue, Professor Franck discusses another experiment in which he and Hertz established that mercury atoms, excited by the bombardment of 4.9-ev electrons, emitted light of only one wave length - 2537 Å.

APPENDIX H

DESCRIPTION OF APTITUDE TESTS

APPENDIX H

Description of Aptitude Tests Used in Spring, 1968

1. The Nelson-Denny Reading Test: Vocabulary-Comprehension- rate

The 1960 revised edition of the Nelson-Denny Reading Test (Form A, for high schools and colleges) was administered. This test gives scores in three areas: vocabulary, reading comprehension, reading rate (not used in this study) and a total score. It is composed of a 100-item vocabulary section and a 36-item reading comprehension section.

Scoring procedure for the Nelson-Denny is as follows: raw scores on the reading comprehension are multiplied by two for each student and added to the vocabulary score for a total. Parallel form reliabilities for reading rate, vocabulary and total score are .92 to .93 while a reliability of .81 for reading is reported. The mean validity coefficient for the vocabulary section is .47; for the reading comprehension section, the mean value reported is .45. Mean difficulties in terms of percentage of students passing the items have been reported as 62 percent for the vocabulary section and 71 percent for the reading comprehension (Orr, 1965). The Nelson-Denny is reported to correlate between .40 and .60 with scholastic achievement (Crites, 1965).

2. Brown-Carlsen Listening Comprehension Test: Evaluation and Adjustment Series

Form BM of the Brown-Carlsen Listening Comprehension Test (1955) (Grades 9-13) was used to measure comprehension of the spoken word. This test is concerned chiefly with those aspects of listening comprehension which distinguish it from silent reading comprehension. An additional emphasis is on the recognition of transitions, reported to be a significant component in useful listening skills. The listening material was presented to the students by tape recorder. Testing time was 45 minutes for questions divided into five areas: (1) immediate recall (17 items); (2) following directions (20 items); (3) recognizing transitions (8 items); (4) recognizing word meanings (10 items); (5) lecture comprehension (21 items).

Reliability based on the Spearman-Brown within-form estimate has been reported to be approximately .86; parallel form reliability has been reported to be approximately .76 (Lorge, 1959).

3. Mathematics Aptitude Test

The 1962 edition of Form R-2 of the Mathematics Aptitude Test was used to measure the mathematical ability of the students.

The test was designed for Grades 11-16 and consisted of mathematical word problems divided into two parts with 15 items each. Ten minutes of testing time was allowed on each part. Solutions were quantitative amounts arranged in the traditional multiple choice style.

No data is currently available on the reliability, validity, or norms for the Mathematcs Aptitude Test (Buros, 1965).

4. Necessary Arithmetic Operations Test

The R-4 form of the Necessary Arithmetic Operations Test (1962) was administered to measure mathematical reasoning ability. The test consisted of problems involving mathematics for which the examinee had to choose the correct operation required to solve the problem, i.e., addition, subtraction, etc. This test was designed for Grades 6-16, and was divided into two parts of fifteen questions each. Five minutes were allowed on each part, for a total of ten minutes testing time.

Data on reliability, validity, or norms for the Necessary Arithmetic Operations Test is not currently available (Buros, 1965).

5. Watson-Glaser Critical Thinking Appraisal

Form AM, of the Watson-Glaser Critical Thinking Appraisal (1956) was used to evaluate reasoning of individuals tested. The test consisted of five subtests in the following areas: (1) Ability to draw correct inferences (20 questions); (2) recognition of assumptions (16 questions); (3) ability to draw appropriate deductions (25 questions); (4) interpretation of date (24 questions); (5) evaluation of arguments (14 questions). Scores were obtained in each of the five areas tested, in addition to a total score.

Split-half and parallel reliabilities for high school students of .79 and .84 have been reported (Hovland, 1959).

6. Logical Reasoning

Form A of the Logical Reasoning Test (Grades 11-16) was also administered. The logical reasoning test measures deduction. Deduction is considered equivalent to sensitivity to logical relationships when judging the correctness of a conclusion. A total of forty questions were divided evenly into two parts, with ten minutes allowed on each part. The questions required correct completion of syllogistic statements. Two valid premises were presented in each item for which the student had to choose the appropriate and logically correct conclusion.

Reliabilities are reported to be .90 for the whole test and .80 for each part. Correlations with various mathematics courses are reported to range from .04 to .42 with a mean of .25 (Howie,1959).

7. Ship Destination Test

The 1965 edition of Form R-3 of the Ship Destination Test was used. The test was designed for Grades 9 and above and was based on factorial analysis of reasoning ability. In particular, arithmetic reasoning was emphasized as contrasted with verbal and analogical reasoning. The test required each subject to perform a series of easy additions and subtractions determined by a set of rules which were different for each set of three items. Complexity of the rules increased with each successive set in order to measure general arithmetic reasoning. The task for each item was described with reference to a ship which progresses from one point to another. The test was described with reference to a ship which progresses from one point to another. The test was composed of 57 ship destination questions, and a total time of fifteen minutes was allowed to complete the test. Test results correlated significantly (.40) with physics achievement. Reliability is reported to range from .86 to .95 (Adock, 1959).

APPENDIX I

SPIELBERGER SELF-ANALYSIS QUESTIONNAIRE

APPENDIX I

Self-Analysis Questionnaire

FORM X-1

Name ______________________________ Date ________________

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel right now, that is, at this moment.

There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	Not at all	Somewhat	Moderately so	Very much so
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I am regretful	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel rested	1	2	3	4
9. I feel anxious	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel "high strung"	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel over-excited and "rattled"	1	2	3	4
19. I feel joyful	1	2	3	4
20. I feel pleasant	1	2	3	4

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FORM X-2

Name ______________________________ Date ________________

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you generally feel.

There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	Almost Never	Sometimes	Often	Almost Always
1. I feel pleasant	1	2	3	4
2. I tire quickly	1	2	3	4
3. I feel like crying	1	2	3	4
4. I wish I could be as happy as others seem to be	1	2	3	4
5. I am losing out on things because I can't make up my mind soon enough	1	2	3	4
6. I feel rested	1	2	3	4
7. I am "calm, cool, and collected"	1	2	3	4
8. I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
9. I worry too much over something that really doesn't matter	1	2	3	4
10. I am happy	1	2	3	4
11. I am inclined to take things hard	1	2	3	4
12. I lack self-confidence	1	2	3	4
13. I feel secure	1	2	3	4
14. I try to avoid facing a crisis or difficulty	1	2	3	4
15. I feel blue	1	2	3	4
16. I am content	1	2	3	4
17. Some unimportant thought runs through my mind and bothers me	1	2	3	4
18. I take disappointments so keenly that I can't put them out of my mind	1	2	3	4
19. I am a steady person	1	2	3	4
20. I become tense and upset when I think about my present concerns	1	2	3	4

APPENDIX J

ATTITUDE RESPONSES FROM STUDENTS

APPENDIX J

Table A

Attitude Toward Using CAI*

		Yes	No	Undecided	No reply
1.	Did you like CAI?	79	16		5
2.	Would you take another course on CAI?	73	16	8	3
3.	Would you recommend CAI P107 to friends?	80	15	5	
4.	Was there less personal contact with CAI?	27	70	3	
5.	Did you like the self-pacing of the CAI course?	95	5		
6.	Did you have a friend taking the regular course?	79	21		
7.	Was the CAI course easier than the regular course?	51	30		19
8.	Would you prefer a CAI exam?	43	33	16	8
9.	Did you feel you gained knowledge via CAI?	90	10		

10.	General Attitude toward CAI Course	Positive	Indifferent	No Preference	No Reply
	Before course	73	5	14	8
	During course	56		14	30
	After course	56	25	16	3

		Yes	No	No Preference	No Reply
11.	Did you prefer the 1500 system to the 1440 system?	53	14	23	10
12.	Did you prefer the use of the light pen to the keyboard on the 1500 system?	78	14	8	
13.	Did you like the use of the 1440 system for review?	70	14		16
14.	Did you prefer multiple choice format to constructed response for review on the 1440 system?	68	14		18

*All numbers are percent of 37 students answering the alternative.

Table B

Student Assessment of Anxiety Scales

1. What did you think was the purpose of the anxiety questions?

   Reaction to (a) the computer - 27
   (b) the course - 19
   (c) the lessons - 21
   (d) the quizzes - 8
   To measure the level of anxiety - 5
   To break the monotony - 3
   Don't know -17

2. Did you respond sincerely to the anxiety questions?

   Always 73 ; sometimes 14 ; never 8 ; no reply 5 .

3. Did you spend much time thinking about your feelings when the questions were presented?

   yes 16 ; sometimes 19 ; no 62 ; no reply 3 .

4. Were the questions appropriately placed in the sessions?

   yes 81 ; no 16 ; no reply 3 .

5. How did you feel about the number of anxiety questions?

   too many 17 ; enough 70 ; not enough 8 ; no reply 5 .

6. Were the questions too long?

   yes 3 ; no 89 ; no reply 8 ;

7. When did your highest point of anxiety occur?

   When taking quizzes - 3
   When taking midterm and final - 3
   When material was difficult - 11
   After poor performance on lessons - 16
   At the beginning of the course - 14
   After leaving the center - 3
   When time was short - 8
   When confused - 5
   When computer not working - 3
   When visitors watching - 3
   Same level throughout - 3
   No anxiety experienced -11
   No reply - 17

Table C

Student Assessment of Course Organization

		Good	Average	Poor	No reply
1.	How would you rate the overall course organization?	63	24	8	5

		Yes	No	No reply
2.	Overall, were the test questions of sufficient quality?	49	27	24
3.	Should there have been more questions?	63	27	10
4.	Should there have been more quantitative problems?	52	43	5
5.	Did you like the textbook?	30	43	27
6.	Were the reading quizzes of sufficient quality?	70	8	22
7.	Were the film quizzes helpful?	60	8	32

8. How would you rate the lecture quizzes?

Thorough - 3 Satisfactory - 49

Poor - 10

9. How would you rate the length of lessons?

Too long - 46 Sufficient - 31

Too short - 3 No reply - 38

		Yes	Undecided	No	No reply
10.	Were the lectures easy to understand?	67		33	
11.	Were lectures the correct length?	70		22	8
12.	Were the supplemental lecture notes easy to understand?	90		10	
13.	Did you prefer the cartridge over the tape deck?	57	14	24	5
14.	Would different voices have enhanced the lectures?	80	10	5	5

Table C - Continued

15.	Were the short films helpful?	62	8	30	
16.	Were the short films easy to understand?	71	8	16	5
17.	How would you rate the amount of information in the film notes?	Too much - 8 Too little - 16	sufficient - 68 No reply -8		

Table D

Student Assessed Areas of Difficulty

1. What concepts in P-107 did you consider to be difficult?

Concept	%	Concept	%
Diffraction	3	Electrostatics	3
Induction	3	Momentum	5
Exponential Notation	3	Quantum Mechanics	3
Magnetic Fields	10	Atomic Physics	5
Electro-magnetic Force	3	Every concept	3
Electricity	19	None	40
Light	8	No reply	3

2. Did you find the math in P107 to be easy or hard?

Easy	Hard	No reply
65	8	27

3. What parts of the course did you have difficulty in remembering?

Topic	%	Topic	%
Magnetic Fields	10	Modern Physics	3
Electricity	14	Formulas	10
Potential	3	Photons and Electrons	3
Electrostatics	3	Lectures	3
Light Properties	5	Films	5
Momentum	3	No retention problem	43

Table E

Student Use of Study Media

1. What was your average preparation time per lesson?

less than ½ hour - 22; ½ hour to 1 hour - 73; more than 1 hour - 5.

2. How did you prepare for the exams?

Computer Review	62	Supplements (audio lectures)	24
Notes (Film,etc.)	46	General Study	3
Book	54	None	3

3. What percent of the long film did you see.

100%	75-100%	50-75%	25-50%	less than 25%
24	43	27	3	3

4. Had you seen some of the long films before?

yes - 30; no - 70.

5. Did you take notes on the long films?

yes - 67; no - 33.

6. Would you use notes if they were furnished?

yes - 73; some of the time - 8: no - 19.

7. How much did you use the FSU film notes?

All of the time - 19; most of the time - 30;

some of the time - 43; no use 8.

8. When did you use the FSU film notes?

before the film - 49; during the film - 35; after the film - 54;

no reply - 8.

9. Did you take notes on the lectures?

yes - 86; no - 14.

Table E - continued

10. How much of the supplemental lecture notes did you use?

all of them - 16; most of them - 52; some of them - 27;

no use - 5.

11. When did you use the supplemental lecture notes?

before the lecture - 24; during the lecture - 93;

after the lecture - 54; no reply - 5.

12. If we were to drop one of the media aids which one would you recommend to be dropped?

film loops - 53 lectures - 14 computer - 3

films - 24 supp.mat.- 3 no reply - 3

Table F

Biographical Data

1. What high school physics did you have?

PSSC*	Regular	None	No reply
33	30	32	5

2. What grade did you receive in high school physics?

A	B	C	No reply
26	15	35	24

(Based on 63% from question 1)

3. What is your college math level?

Up to and including basic college math 57
Above basic college math 23

4.

Sex	Percent
Male	46
Female	54

5. Class Distribution:

Freshman	Sophomore	Junior	Senior
62	8	8	23

*Physical Science Study Committee on High School Physics.